PLANTERS' RECORD

VOL. XXXVII

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

THE HAWAIIAN PLANTERS' RECORD

VOL. XXXVII

H. P. AGEE, *Editor*

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HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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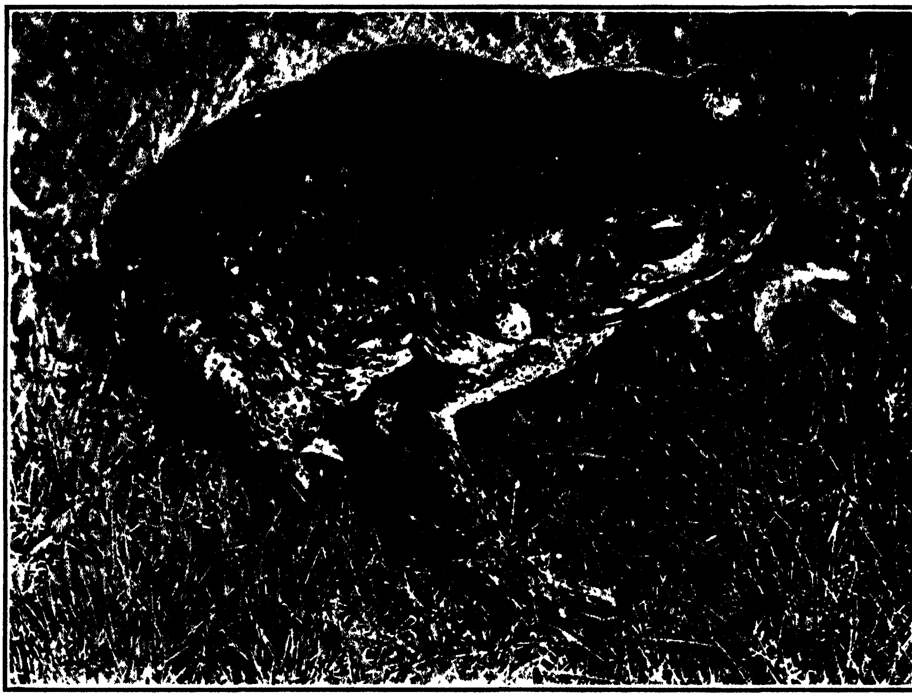


BUFO MARINUS
Tropical American Toad
Introduced into Hawaii from Porto Rico in April, 1932.

SECOND QUARTER

Two of the new hybrids between H 109 and P. O. J. 2878.

THIRD QUARTER

The historical irrigation ditch built by W. H. Rice at Lihue in 1856. At present, considerably enlarged, this ditch, through the German Forest, follows the route of the first irrigation canal for sugar cane in Hawaii. (Original photograph taken about 1885; courtesy of Miss Ethel M. Damon and Mrs. Dora H. Isenberg.)

FOURTH QUARTER

Breeding Canes in Tassel—Kailua Variety Station.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVII FIRST QUARTER, 1933 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Introduction of Tropical American Toad:

Description is given of an insectivorous toad with discussion of its introduction to Hawaii, habits, establishment and probable value together with an account of its history and usefulness in Porto Rico.

Improved Arsenical Dust for Armyworms:

Arsenical dusts containing a small amount of neutral mineral oil have proven superior to dusts used previously against armyworms, because of better sticking qualities. Formulae are included with method of preparation and results of tests.

Introduction and Habits of New Grasshopper Parasite:

An account of the discovery in Malaya of an egg parasite of the Chinese grasshopper is presented with an outline of its habits, introduction to Hawaii, local breeding, distribution and establishment.

Some Food Habits of the Mongoose:

A detailed enumeration of the food eaten by a number of caged individuals and of intestinal contents from this animal in the field, indicates a wide variety of material eaten, with a strong preference for animal rather than vegetable food.

Annual Synopsis of Mill Data:

The Annual Synopsis of Mill Data for 1932 is presented. The statistical data and discussion of technical results are in much the same form as in previous years.

Notes on Seedlings on Kauai:

Several of the seedlings which are being tested on Kauai are discussed.

Scales and Their Troubles:

A discussion on scales is given by the inspector employed by the Association under the auspices of the Raw Sugar Technical Committee. The weak and strong points of certain types of scales are dealt with and practical hints are given on keeping scales in good working condition.

The Bindweed:

An illustrated account is given of the appearance and habits of the California morning-glory or bindweed, a cane field pest of potentially great importance, and suggestions are made as to methods of control.

Chromosomes of Sugar Cane:

Illustrations of sugar cane chromosomes are presented with a discussion of the role of chromosomes in the mechanism of heredity.

Measuring Production in Terms of Temperature:

The marked influence of temperature on cane growth is well recognized in these islands. In the present paper an attempt has been made to devise a quantitative measure of temperature as affecting cane growth and yield. It is shown that with the help of this new measure called the "day-degree" satisfactory estimates of total effective warmth for different crops may be easily obtained.

It is suggested that this new measure, approximate though it may be, provides us, nevertheless, with a strong tool, an intelligent use of which may aid our future agricultural progress.

Lime Versus No Lime:

In summarizing the results of lime experiments, little or no evidence has been found that lime has affected the cane tonnage. It would seem to be more than a coincidence that in practically all cases the quality ratio was slightly better in the no lime plots. A further study of the quality ratio figures shows that the Brix, polarization and purity are lower on the limed than on the unlimed plots. This holds for the acid wet and semi-dry areas on Hawaii and Kauai, as well as on the more or less neutral irrigated lands of Oahu and Maui.

The Effect of Various Intensities of Light on the Growth of the H 109 Variety of Sugar Cane:

The results of a preliminary experiment on the effects of various intensities of light on the growth of H 109 cane are given. With decreased light intensity the height of the primary stalks was increased, secondary shoot development was completely retarded, the leaves became narrow, elongated, and brittle, and the root development was greatly reduced. The dry matter of the plants was also reduced with decreased light intensity. With decreased light the chlorophyll content of the leaves was increased up to a certain point, but with the further decreased light the chlorophyll content was reduced.

Invertase Activity in Sugar Cane:

Data are presented which indicate that the activity of the enzyme invertase is seriously affected by a deficiency of potash in sugar cane.

The results herein reported offer indirect evidence that sucrose in the sugar cane plant is synthesized by invertase.

P. O. J. 36 on the Big Island

A point of real interest in cane culture on the island of Hawaii is the extent to which the cane variety P. O. J. 36 is being spread. The planting programs of 1932 caused the seventeen plantations of that island to place an additional area of 3,797 acres under P. O. J. 36, bringing the total area for the 1933 and 1934 crops to 10,181 acres.

The plantation with the largest area of P. O. J. 36 at the beginning of this year is the Onomea Sugar Company, with 1,931 acres; followed by Hutchinson Sugar Plantation Company, with 1,154 acres. Thus is indicated the suitability of this variety for both wet and dry areas of the Big Island. Third comes Paauhau Sugar Plantation Company, with 1,116 acres; fourth, Olaa Sugar Company, with 1,087 acres; fifth, we have Hakalau Plantation Company, with 1,010 acres; sixth, Honomu Sugar Company, with 1,006 acres; and seventh, Honokaa Sugar Company, with 971 acres. The remaining plantations have smaller areas varying from 379 acres at the Hawaiian Agricultural Company, to 16 acres at Kaiwiki Sugar Company.

If we consider this expansion of P. O. J. 36 on the part of the different plantations in terms of the percentage of the total cane area that has been placed in this Java seedling, we find another interesting listing, which gives Honomu first place, with 30% of their total area in P. O. J. 36, followed by Onomea, with 24.5%; Paauhau, with 24.4%; Hutchinson, with 21%; Hakalau, with 15.5%. Studied from this angle, the five Brewer plantations named above hold the lead

by a good margin. Sixth comes Honokaa, with 10.3%; then Niulii, with 8%; Pepeekeo, with 7.8%; Olaa, with 7%. Then come Hilo Sugar Company, with 4.8%; Union Mill, with 4.3%; Hawaiian Agricultural Company, with 3.8%; Kohala Sugar Company, with 3.4%; Laupahoehoe Sugar Company, with 2.7%; Hamakua Mill, with 2.2%; Waiakea Mill, with 0.8%; and Kaiwiki, with 0.4%.

P. O. J. 36 AREAS IN 1933 AND 1934 CROPS

Plantation	P. O. J. 36 Area	Total Area in Cane	% of Total Area in P. O. J. 36
Hakalau Plantation Company	1,010	6,494	15.5
Hamakua Mill Company	140	6,272	2.2
Hawaiian Agricultural Company	379	10,000	3.8
Hilo Sugar Company	374	7,817	4.8
Honokaa Sugar Company	971	9,393	10.3
Honomu Sugar Company	1,006	3,312	30.0
Hutchinson Sugar Plantation Company	1,154	5,380	21.0
Kaiwiki Sugar Company	16	4,613	0.4
Kohala Sugar Company	347	10,115	3.4
Laupahoehoe Sugar Company	170	6,415	2.7
Niulii Mill & Plantation	196	2,450	8.0
Olaa Sugar Company	1,087	15,618	7.0
Onomea Sugar Company	1,931	7,876	24.5
Paauhau Sugar Plantation Company	1,116	4,563	24.4
Pepeekeo Sugar Company	286	3,682	7.8
Union Mill Company	132	3,054	4.3
Waiakea Mill Company	46	5,794	0.8

The plantations on Hawaii will spread P. O. J. 36 still further this year, and from the forecasts of 1933 plantings that are beginning to be returned it is evident that the area of this cane will be extended by many hundreds of acres.

H. P. A.

Improved Arsenical Dust for Armyworms

By C. E. Pemberton

During the summer of 1932, field tests with arsenical dusts, into which had been incorporated a small percentage of neutral mineral oil, were made in an effort to improve the sticking qualities of these dusts. The oiled dusts adhered to the cane leaves distinctly better than the others. The final formulae as now recommended are as follows:

Finely powdered raw rock phosphate	6 parts
White arsenic	1 part
Neutral mineral oil	5 per cent
or	
Finely powdered raw rock phosphate	5 parts
Powdered arsenate of lead	1 part
Neutral mineral oil	5 per cent

Proportions by weight.

The particular dust used in the tests was prepared by the Pacific Guano and Fertilizer Company. The oil is described as Shell Zero Oil and is a commercial neutral spray oil. Flint and Farrar*, who have developed mineral oil insecticide dusts in Illinois, found that mineral oils of from 80 to 110 seconds viscosity were most desirable for dusting mixtures. The oil is inert and is not injurious to the cane leaves in the proportions used. It is best mixed into the finally prepared dust by atomizing or spraying it under considerable pressure over the dust while the latter is being stirred or agitated. In the preparation of small amounts the oil can be sprayed over the thoroughly stirred dust with a flit gun or simple hand sprayer. The best method for thoroughly mixing the oil is to spray it into a hopper or drum while the dust is slowly added.

Oiled dusts do not pack in storage nor deteriorate.

Field tests at Hilo Sugar Company by Dr. F. X. Williams, and in Manoa Valley by R. H. Van Zwaluwenburg, at times when considerable rain fell, gave distinctly better adhering qualities of the oiled dusts over others.

Analyses by the chemistry department of the residue left on cane leaves which had been dusted with several arsenic mixtures by Mr. Van Zwaluwenburg in Manoa Valley in July, 1932, indicated that oiled dusts adhered much better than would appear to the eye in field examinations. Leaf samples from the field which had been dusted with one part white arsenic and six parts raw rock phosphate to which 5 per cent by weight of mineral oil had been added, showed in all samples taken over twice as much arsenic present as on leaf samples receiving any other mixture. In some cases over three times as much arsenic was

* The Use of Mineral Oils for Better Dusts. *Journal Economic Entomology*, Vol. XXV, pp. 269-271, April, 1932.

present. These tests compared white arsenic and raw rock phosphate mixtures with and without oil; calcium arsenate and raw rock phosphate mixtures with and without one part cement, and thirdly white arsenic and raw rock phosphate mixtures with and without one part cement. All of the tests received over two inches of rainfall before sampling began.

Notes on Seedlings—Kauai

28-3540 is attracting particular interest at Kekaha Sugar Company. The plantation has planted approximately 40 acres of this seedling on their Mana flats and in all cases it is making a satisfactory growth.

This is a seedling of Yellow Caledonia crossed with H 109. It is completely eye spot resistant, but takes brown stripe in the locations where this disease is prevalent. In general, it produces a stalk slightly larger than H 109 and has an upright habit of growth. It ratoons well.

28-2055 is rapidly coming to the front at Koloa Sugar Company. The preliminary yields from the plant crop were most satisfactory and the ratoons have been most vigorous and economical in weed control.

This seedling is a half-sister of P. O. J. 2878 in that it has the same female parent. The male parent is a Caledonia hybrid, 26 C 270. It may be considered commercially resistant to eye spot disease in that it shows only an occasional runner. The stalks of this seedling are of medium size and tend to tassel heavily. Strong lalas develop soon after the tassels emerge.

30-2417 is a new seedling which is attracting great interest wherever it is planted. It germinates well, develops large, clean stalks which show a rapid rate of growth. Eye spot and brown stripe are no problem with this seedling. Little is known about the juice quality of this new seedling yet, although the parentage (28-674 [POJ 2364 × 26 C 270] × H 456) would indicate that this should be good.

Co. 290 is making a rank growth wherever it is planted. On all the plantations on Kauai where eye spot is prevalent the disease was most severe on Co. 290. In three cases it was found necessary to dig the cane out to prevent the spread of the disease from these plots to the adjoining fields.

C. G. L.

Introduction to Hawaii and Habits of Egg Parasite of Chinese Grasshopper

By C. E. Pemberton

The Chinese grasshopper *Oxya chinensis* (Thun.) is undoubtedly of Oriental or Indo-Malayan origin. The genus Oxya is known to contain some 30 species, most of which occur in India or Indo-Malayan regions. The species *chinensis* most probably reached Hawaii in the egg stage in soil brought to Hawaii by Orientals during the early days of labor importations.

In undertaking the problem of finding parasites of this grasshopper in 1930, the Malay Peninsula was chosen for study because *O. chinensis* was known to occur there, in company with a half dozen or more species of the same genus.

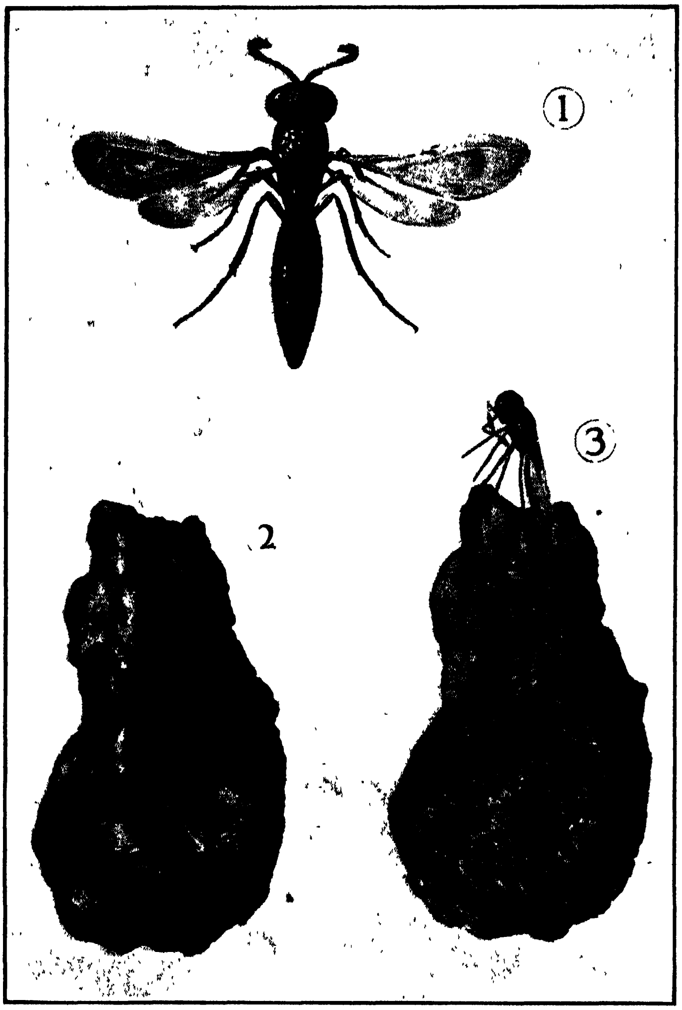
The writer departed for Malay on July 8, 1930, and reached Serdang, Selangor, Federated Malay States, on August 12, where quarters were obtained near virgin forest and open cultivated land through the kindness of the Department of Agriculture, F. M. S. This region lies about 175 miles up the Peninsula from Singapore. Oxya grasshoppers though present were never abundant. It was seldom possible to find more than 40 in a day's time though in rice fields in Malaya they are said to become abundant at times.

Field cages open at the bottom and resting directly on the ground and covered with large mesh wire screen were set out in grassy land. These were stocked with grasshoppers, which immediately started laying their eggs in the soil under the cages. The eggs were periodically removed and held in stoppered vials for observation. After seven weeks of such work two species of parasites were reared from the Oxya eggs. These parasites, since described and named by P. H. Timberlake as *Scelio serdangensis* and *Scelio pembertoni*, which are new species, were reared in quantity between October, 1930, and April, 1931, and shipped to Honolulu. Thirteen shipments of parasitized grasshopper eggs were made, from which 2600 parasites were successfully reared in Honolulu by O. H. Swezey and his associates.

Between January, 1931, and January, 1933, a total of 44,300 parasites have been reared in the laboratory in Honolulu on *Oxya chinensis* eggs and distributed to sugar plantations in Hawaii. Most of the distribution has been of the species *Scelio pembertoni*. The other species *S. serdangensis* died out in the cultures early in 1931. The breeding work since August, 1932, has been conducted by J. S. Rosa.

The extensive breeding and distribution of the parasites has already resulted in the known establishment of the species *S. pembertoni* in several localities on the island of Oahu and at Hilo Sugar Company on the island of Hawaii. The life history of this species may be briefly summarized as follows:

The female searches over the ground for spots where the grasshopper has deposited egg pods. Upon locating one she works through the loose soil particles



Malayan parasite of Chinese grasshopper.

1. Adult female. × 9.

2. Grasshopper egg-pod from which parasites have hatched. × 5.

3. Parasite inserting eggs in grasshopper egg-pod. × 5.

which more or less cover the mass of 15 to 25 eggs and inserts her ovipositor therein usually in the manner and position indicated in Fig. 3. She places one egg each in several or all of the grasshopper eggs in the egg pod. In order to accomplish this the parasite may remain in the ground over the grasshopper egg mass for from a half hour to sometimes 4 or 5 hours with hardly any change of position. Occasionally more than one egg will be placed in a single grasshopper egg. In such cases all of the parasite eggs hatch but only one parasite ultimately develops in the egg.

The parasite lives about two weeks and deposits an average total of approximately 50 eggs.

From 25 to 40 or 50 days after the eggs are laid, depending on the temperature, the parasites hatch from the Oxya egg pod. They escape by gnawing their way out. An egg pod from which parasites have hatched is shown in Fig. 2 and the parasite, much enlarged, in Fig. 1.

Almost immediately after the female parasite hatches from a grasshopper egg she is capable of ovipositing. An abundance of mature eggs are present in the ovaries at this time. The parasite successfully parasitizes grasshopper eggs of all ages. Hopper eggs almost ready to hatch can be successfully parasitized as well as those newly laid or at all ages between the two extremes.

If the parasite cannot find eggs for at least two weeks after hatching she still is able to successfully parasitize eggs for a day or two before dying.

Females are usually much more numerous than males.

Mr. Swezey has shown that the development period of the grasshopper from egg to adult averages in Hawaii from 12 to 16 weeks. From the above summary it is seen that the period required for development of the parasite, from egg to adult, varies from 4 to 7 weeks with an average of about 5 weeks. The parasite thus requires only about one-third as much time to pass through a cycle as the grasshopper.

A more detailed account of this parasite has been prepared for publication in the *Proceedings of the Hawaiian Entomological Society* for the year 1932.

Scales and Their Troubles

By C. P. Hinman

A desirable scale is one which will give accurate weight of an article and continue to give accurate weight over a reasonable period of time.

To give such results, the scale must be suited to the work it has to do. It must be of sufficient capacity to withstand the load, plus the shock attending the placing of the load on the scale. All scales to which the load is roughly applied should have a rated capacity of ten times the amount of the usual load weighed.

Cane-car scales of this rating will stand up under long years of service, giving a continuous correct weight. For example, the scales at Olaa, Paauhau and Honokaa have been in service for more than 30 years and no repairs have yet been necessary to the main levers. On the other hand, the 10-ton rated capacity "A" lever scales, at a number of mills where they are used for weighing loaded cane cars, have not stood up to accuracy more than two years without adjustment of main levers. At three plantations, scales which were taken out and refitted with new steels in 1928 were so worn that they had to be taken out and reground in 1932. Four years of service for these scales against 30 years, and more to come, for the Olaa scales.

The juice scales used in all but two of the mills are of a single make. Some of these have been in service more than 20 years with no repairs to the main levers. They are the best scales for this work that can be bought today. The type recording beam used on these scales requires repairs at least once a year. The rollers, track, stamping device, and the poise latch are constantly wearing, changing the efficiency and accuracy of the scale. The poise on the average juice scale travels something like 700 feet every 24 hours on rollers 1⅛ inches in diameter, making about 30 miles of travel in a grinding season.

The sugar sacking scale which has shown the best results in the past four years is a 1,000-pound capacity portable scale. This scale has ball-bearings under the platform which keep the platform clear of the frame, and the scale will give accurate weights when not exactly level. Other scales having check rods to hold the platform from the frame have not given satisfaction. The flat bearing at the front of the platform permits the short lever to slide under it, changing the relative position of the two main levers, and the multiple of the scale is changed, giving weights over or under the true weight. The rough placing of a sack of sugar on such scales will cause the change mentioned.

Other scales having indicators to mark the high or low balance of the weighbeam have been tried in two or three mills. Like all scales, their sensitiveness depends upon their cleanliness. This type of scale is good, beyond question, but its cost is fifteen times or more than that of the 1,000-pound scale, mentioned in the preceding paragraph, and the accuracy of the weight is dependent upon the man doing the weighing. The human element cannot be removed from sugar sacking at present with any degree of improvement. The automatic sugar scale

is not a success in raw sugar sacking and reports will show that better weights are obtained on the plain portable scale with a careful man doing the weighing.

In cane-car weighing, the human element has been largely removed at many mills by attaching the weightograph to the weighbeam. The weightograph automatically balances the platform load and the correct weight is shown in figures of light on a ground glass panel similar to that of a movie screen. The combined weight shown there is copied by the weighman on the weighsheet. Of the numbers of these machines in use at the mills for years past there are no complaints and each owner is well satisfied with them.

The old style weighbeam required the placing of weights at the end of the beam and sliding a poise to a point where the beam balanced. The several weights must then be combined into one for entry. The type-recording beam combined the weights into one and stamped them on a cardboard strip. In neither case is there any assurance that the beam was in balance at the time the reading was made. The balancing of the beam was entirely dependent upon the reliability of the weighman. The stamped weighticket meant that the poise was at that location when the ticket was stamped. It may have been hundreds of pounds above or below the true weight. The weightograph eliminates this doubt. The figures on the screen are more easily copied than it would be to invent another set of figures. In addition to this, a device has been granted a patent which will automatically make a record of the weights shown on the weightograph, entirely eliminating the human element. This may be placed on the market before the next grinding season.

Juice weight accuracy would be greatly improved by the attachment of the weightograph to juice scales.

The following is a summary of the work during the past offseason up to December 1:

The mills were a month late shutting down in 1932, making it necessary to work Sundays and some nights and longer hours than usual in order to service all the scales at all the plantations.

Of the 40 mills and railroads to be serviced this year, up to December 1, 36 of them had been serviced. At these 36 plantations and railroads, 301 scales were serviced.

All scales were left weighing correct within the tolerance. The tolerance is the permissible error, over or under the true weight, allowed by the United States Bureau of Standards, and a scale weighing within the tolerance is assumed to be correct in all States on the mainland. The tolerance, or permissible error on plantation mill scales, is one-tenth of 1 per cent.

Sixty-eight standard 50-pound test weights were compared with the master weight and made correct.

Reports to the plantation managers, and the Experiment Station, have been made on each scale serviced or inspected. Certificates of the accurate condition of cane-car scales and railroad scales have been issued to the plantation managers, showing date of final test.

Some Food Habits of the Mongoose

During August, 1932, we were informed, through J. W. Waldron, of mongoose injury to bananas at the property of Miss Wilhelmina Tenney at Heeia, Oahu. Miss Tenney had observed this animal actually carrying bananas away. In Trinidad, bananas have been sometimes used successfully as bait in mongoose traps. To further test this and other habits of the animal a number were caged at the Waipio substation and fed a varied diet. This was greatly facilitated through the help of F. C. Denison and his staff at Waipio, who conducted most of the feeding tests.

It was found that the mongoose would not eat sugar cane even when split, nor such fruit as papaias and oranges, but that ripe bananas and their skins would be eaten, especially the skins at times when more acceptable food was not available. Fresh coconut meat if removed from the shell is eaten in small amounts, but rancid coconut is avoided. Bread, rats, mice, eggs (no shells), birds, fish, live crabs, centipedes, cockroaches, all insects, frogs, earthworms, and meat of all sorts were usually taken with relish. They would not eat millipedes. A good deal of water was taken. When confined together some of the less pugnacious individuals were killed and eaten by their associates.

At Oahu Sugar Company we frequently find remains of Anomala adults in the mongoose excrement together with mouse and rat hair and other insects such as grasshoppers and cockroaches.

Mongoose *Herpestes birmanicus.* About one-quarter natural size.

As reported on page 42, Bulletin No. 17, Entomological Series, of this Station, the writer made 356 examinations at Honokaa, Hawaii, in 1924, to determine the food consumed in the field by the mongoose and found in all cases nothing but the remains of rats, mice, or insects, alone or in combination.

During 1915-1919 and 1920, O. H. Swezey made a number of examinations of mongoose excrement from Palolo Ridge, Oahu (near the crater), Waiau Ridge, Oahu, Mt. Tantalus, Oahu, the H. S. P. A. Experiment Station, Honolulu, Waianae above the plantation, and upper Moanalua Valley. In every case he found either insects, spiders or rodent parts, or combinations of them. The findings included remains of crickets, grasshoppers, the locustid *Conocephalus saltater,* rodent hair or bones, the grasshopper *Oxya chinensis,* Scotorythra caterpillars, spiders, the rose beetle *Adoretus sinicus,* the ground beetle *Gonocephalum serriatum,* a few honey bees and the large wasp Polistes (probably hebraeus). He found in a few cases guava seeds and bits of grass.

C. E. P.

Studies of the Invertase of Sugar Cane

A Preliminary Report*

By Constance E. Hartt

Oparin and Kurssanov (1) report the synthesis of a sugar identified as sucrose from an invert sugar solution in the presence of phosphate salts by the simultaneous action of the invertase and phosphatase of yeast. This work has a direct bearing upon the results recently obtained in connection with studies dealing with some effects of potassium upon the growth, chemical composition and enzyme activity of sugar cane, which will be reported in full elsewhere.

In a previous report (2) evidence was presented indicating that sugar cane plants deficient in potassium have weaker invertase than similar plants supplied with an adequate amount of potash. These experiments have been repeated and elaborated during the past year.

Sugar cane, variety H 109, grown in quartz sand and supplied with a complete nutrient solution containing 87.9 p.p.m. K, when tested for invertase showed an activity greater than that in plants deficient in potassium, in both stems and blades. The activity in stems was affected more severely by a lack of potassium than that in blades. Invertase was determined by the method described in the former paper, using the Bertrand titration. The results are presented in the table, in which the figures for invertase activity are expressed in cubic centimeters of $N/20\ KMnO_4$.

* This research was conducted in 1931-1932 at the Experiment Station of the Hawaiian Sugar Planters' Association, with the aid of the Sarah Berliner Research Fellowship of the American Association of University Women.

K DEFICIENCY AND INVERTASE ACTIVITY

Series No. of Plant	p.p.m. K in Soln.	% K		Invertase–Unbuffered		Intertase at pH 4.4	
		Blades	Stems	Blades	Stems	Blades	Stems
1	87.9	2.175	1.504	25.00	22.16	36.08	23.04
5	0.0	0.501	0.278	17.71	7.97	36.69	13.57

It is interesting that the invertase activity in the blades was equalized at the optimum reaction (pH 4.4) while that of the stems was not.

Sugar determinations were performed and derangements in the transformations of hexoses and sucrose were noted in the plants deficient in potassium, correlated with their weak invertase activity.

In another experiment, using variety P. O. J. 2878, it was found that the invertase activity of the green leaf portion of the stalk was double that of the dry leaf part of the stem. Green leaf cane may be defined as that portion of the stalk to which green leaves are attached; the part which bears only dry leaves is called dry leaf cane. It is in the green leaf part of the stem that the most active storage of sucrose occurs. Some additional storage takes place in the dry leaf cane. The invertase of the blades was found to be equal in activity to that of the green leaf cane. It is evident that wherever sucrose is actively formed and stored, the activity of invertase is great, whereas where the process of storage is practically completed, invertase decreases in activity.

For many years the order of the formation of sugars in the plant has been a moot question. Clements (3) has recently stated that physiologists seem to agree now that the simple sugars are the first sugars formed by plants; and Priestley (4) concluded that the hexoses are the primary sugars of photosynthesis. The results of the present study also support this view. If sucrose were the first sugar formed in photosynthesis in sugar cane, then it must be considered that all the glucose and fructose in the blades is formed by the inversion of sucrose. If so, then what is the explanation of the greater percentage of reducing sugars and lower percentage of sucrose, with equal total sugars, in the potassium-deficient blades, which had the weakest invertase activity?

It would seem that these results offer indirect evidence that sucrose in the sugar cane plant is synthesized by invertase.

Further studies of the factors affecting the activity of invertase in sugar cane are now under way.

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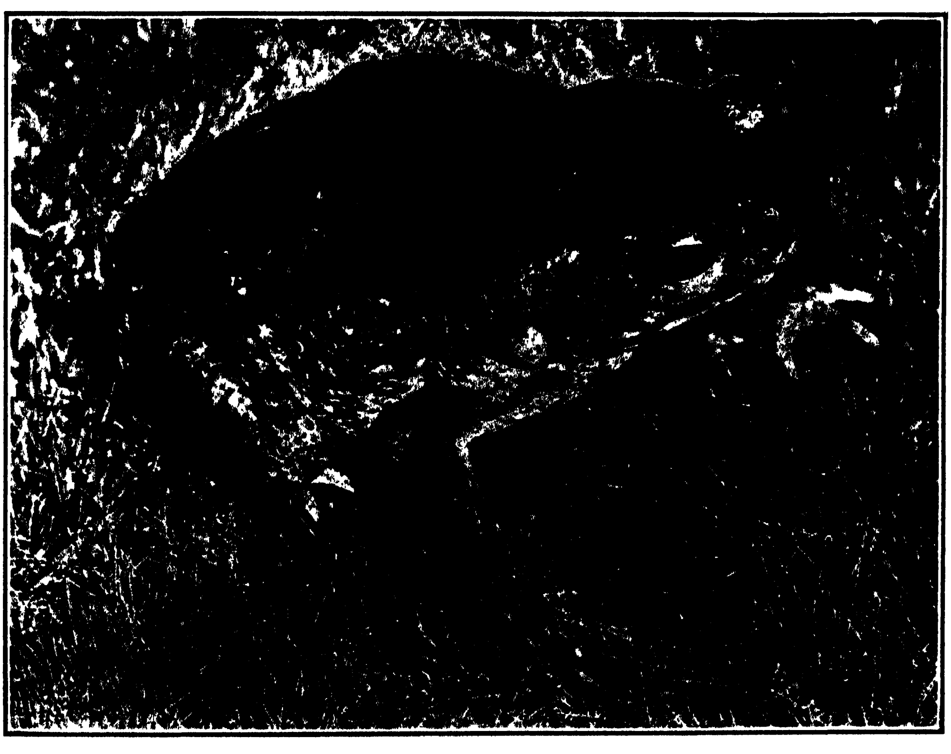
Introduction to Hawaii of the Tropical American Toad *Bufo marinus*

By C. E. Pemberton

During March and April, 1932, the writer collected in Porto Rico and imported to Hawaii, 154 toads of the species *Bufo marinus* (Linné) of which 149 arrived in good condition and were liberated in upper Manoa Valley and at Waipio on the island of Oahu. The toads were transported in four separate lots, each lot being confined in a wooden box nearly filled with wood shavings or excelsior. The first three consignments were sent by regular express and the fourth crate personally conveyed by airplane from Porto Rico to Florida, by transcontinental train from Florida to California and thence by steamer to Honolulu. The first three lots arrived in Honolulu after a journey of from 16 to 19 days and the fourth reached its destination in 13 days. No food was given them en route. The packing material in each box was thoroughly moistened in Porto Rico before shipment.



Bufo marinus. **One-half natural size.**

The toads were liberated at Waipio on April 22 and 30 and in Manoa Valley on April 18 and 29. For several months after liberation some of the original toads have been seen at various places near by but in a few cases individuals have been observed several hundred yards distant from the points of liberation. On August 31, 1932, several young toads were seen at Waipio and from then on they have been readily found in this locality. This is fair indication that the species has become established. It will probably be a year or more before they have become sufficiently numerous to be moved in quantity to other portions of Hawaii.

Bufo marinus is native to tropical America and is known to occur from Mexico to northern Argentina, including the island of Trinidad. It has been purposely distributed by man in modern times to a number of the West Indian islands and Bermuda because of its insectivorous habits. Wherever introduced it usually remains comparatively inconspicuous for a few years and then appears in great numbers and continues abundant. The Federal Agricultural Experiment Station of Porto Rico introduced it to that island from Barbados in 1920, and in 1924 R. Menéndez Ramos, director of the Insular Experiment Station at Rio Piedras, P. R., introduced 40 more of the same toad from the island of Jamaica. The toads increased very rapidly, for in the Annual Report of the Porto Rico Agricultural Experiment Station for 1926, the director, D. W. May, stated that the toads had "increased so rapidly that now they are found in great numbers in the western end of the island." He stated further that "Planters in this part of the island report lessened depredations of the changa" (mole cricket) "and white grubs" (allied to Anomala and Adoretus) "as a probable result of the introduction."

This toad will eat almost any insect that comes within its vision, which includes beetles, moths, wasps, flies, caterpillars, mosquitoes, etc. It is mostly nocturnal, hiding generally by day in holes in the ground. Occasionally they can be seen in the daytime, especially when very numerous in a particular locality. They have become very abundant in Porto Rican cane fields and are credited today with helping considerably in checking certain pests of cane. The tadpole stage is said to be of short duration compared with that of most other toads and frogs.

This toad when full grown will measure from 6 to 7 inches in body length. There is every possibility that it will become very numerous in Hawaii because of the absence of many natural enemies which it normally contends with in its native habitat. It was found to thrive in Porto Rico even in cane lands occupying the dry sections of the island. Small ponds, reservoirs and temporary pools during short rainy seasons seem sufficient to enable it to multiply rapidly and radiate into agricultural lands away from water.

Lime Versus No Lime

In summarizing the results of these 19 lime experiments, we find little or no evidence that the lime has affected the cane tonnage, but it would seem to be more than a striking coincidence that in practically all cases the quality ratio was slightly better in the no lime plots. Further study of the components of these Q.R. figures shows that the Brix, polarization and purity are lower on the limed than on the unlimed plots. This holds for the acid wet, and acid semi-dry areas on the islands of Hawaii and Kauai as well as on the more or less neutral irrigated fields on Oahu and Maui.

Following this hint we are planning work to see what effect, if any, will changing the pH of coral soils with sulphur, or of acid soils with lime have on the juices. A careful study of the plant itself will be made. Generally the low coral flats have poorer juices. Is this in any way related to lime?

However, we must not overlook the fact that lime is one of the absolutely essential nutrients of plants, and in connection with our studies of the effects of lime on cane juices we must also concern ourselves with maintaining adequate reserves of calcium to be drawn upon by our crops.

A COMPARISON OF JUICES WITH AND WITHOUT LIME

	Expt.	Brix		Pol.		Pur.		Q. R.	
Plantation	No.	Lime	No Lime	Lime	No Lime	Lime	No Lime	Lime	No Lime
Hilo Sugar Co.......	27	19.26	19.57	17.12	17.48	88.92	89.32	7.76	7.60
Honomu Sugar Co. .	22	12.75	13.93	10.58	12.12	83.0	87.0	13.23	11.14
" ...	23	15.70	17.03	13.36	14.97	85.1	87.9	10.22	8.89
Pepeekeo Sugar Co..	5	18.82	18.62	17.03	16.67	90.44	89.53	7.74	7.94
Hakalau Plt. Co....	17	18.10	18.3	16.0	16.2	88.4	88 5	8.34	8.24
Totals		84.63	87.45	74.09	77.44				
True Averages		16.93	17.49	14.82	15.44	87.5	88.6	9.01	8.55
Kaiwiki Sugar Co...	1	19.7	19.9	17.75	17.90	90.1	89.9	7.44	7.22
" ...	4	19.3	19.8	17.5	18.0	89.6	90.9	7.63	7.26
Hamakua Mill Co...	1	18.13	18.5	16.26	16.85	89.7	91.03	7.90	7.55
Paauhau Sug. Plt. Co.	10	17.31	17.48	15.71	15.88	90.76	90.85	8.30	8.20
Niulii Mill & Plt. Co.	1	17.88 =	17.87	15.70	15.84	87.81	88.64	8.65	8.43
Union Mill Co......	21	18.93	19.59	16.90	17.62	89.28	89.95	7.88	7.53
Totals		111.25	113.14	99.62	102.09				
True Averages		18.54	18.86	16.60	17.02	89.5	90.2	7.93	7.70
Kilauea Sug. Plt. Co.	4	17.27	17.63	15.06	15.31	87.2	86.6	8.80	8.68
Lihue Plantation Co.	11	14.66	14.5	11.72 =	11.7	79.94	80.7	12.40	12.30
Grove Farm Co.....	8	18.09	17.93	15.77 =	15.74	87.2	87 8	8.43 =	8.41
Koloa Sugar Co.....	30	14.62	14.70	12.12	12.23	82.8	83.2	11.55	11.45
"	20	15.3	15.6	11.93	12.67	77.9	81.2	12.38	11.08
Totals		79.94	80.36	66.60	67.65				
True Averages		15.99	16.07	13.32	13.53	83.3	84.2	10.36	10.12
Wailuku Sugar Co..	1	20.93	21.81	18.82	19.66	89.92	90.18	6.97	6.66
Oahu Sugar Co.....	8	16.5	16.9	14.11	14.66	85.54	86.16	9.66	9.24
"	17	15.5	15.6	12.45	12.58	80.18	80.9	11.18	11.06
Totals		52.93	54.31	45.38	46.90				
True Averages		17.64	18.10	15.13	15.63	85.8	86.4	8.94	8 61
Grand Average		17.36	17.67	15.09	15.50	86.56	87.42	9.21	8 85

SUMMARY—NO LIME PLOTS—JUICE

	Better	Equal	Poorer
Brix	15	1	3
Polarization	18	2	1
Purity	17	1	3
Q. R.	18	1	2

NOTE—Best underscored. Equal sign used when no difference.

LIME VS. NO LIME

Plantation	Expt. No.	Q. R. Lime	Q. R. No Lime	Sugar per Acre Lime	Sugar per Acre No Lime	Gain or Loss Sugar for Lime Plots	Variety
Hilo Sugar Co.	27	7.76	7.60	10.79	10.01	+0.78	Y. C.
Honomu Sugar Company	22	13.23	11.14	4.70	5.39	— .69	D 1135
"	23	10.22	8.89	7.10	7.60	— .50	Y. C.
Pepeekeo Sugar Company	5	7.72	7.94	6.45	6.52	— .07	Y. C.
Hakalau Plantation Co.	17	8.34	8.24	5.59	5.62	— .03	Y. T.
Totals		47.27	43.81	34.63	35.14		
Averages		9.45	8.76	6.93	7.03	— .10	
Kaiwiki Sugar Company	1	7.44	7.22	5.65	5.67	— .02	Y. C.
"	4	7.63	7.26	3.21	3.39	— .18	Y. C.
Hamakua Mill Company	1	7.90	7.75	1.93	1.98	— .05	D 1135
Paauhau Sugar Plt. Co.	10	8.30	8.20	5.62	5.57	+ .05	D 1135
Niulii Mill & Plt. Co.	1	8.65	8.43	1.92	1.80	+ .12	Y. C.
Union Mill Company	21	7.88	7.53	6.45	6.20	+ .25	Striped
Hawi Mill & Plt. Co.	2	7.88	7.93	6.86	6.59	+ .27	D 1135
Totals		55.68	54.32	31.64	31.20		
Averages		7.95	7.76	4.52	4.46	+ .06	
Kilauea Sugar Plt. Co.	7	8.55	8.54	3.73	3.69	+ .04	Y. C.
"	4	8.80	8.68	3.09	2.94	+ 15	Y. C.
Lihue Plantation Co.	11	12.40	12.30	3.70	3.60	+ .10	Y. C.
Grove Farm Co., Ltd.	8	8.43	8.41	4.84	4.98	— .14	Y. C.
Koloa Sugar Company	20	12.38	11.20	3.09	3.00	+ .09	Y. T.
"	30	11.55	11.45	4.91	4.67	+ .24	Y. T.
Totals		62.11	60.58	23.36	22.88		
Averages		10.35	10.10	3.89	3.81		
Wailuku Sugar Company	1	6.97	6.66	12.40	12.18	+ .22	Lahaina
Oahu Sugar Company	8	9.66	9.24	8.45	7.96	+ .49	Lahaina
"	17	11.18	11.06	6.03	6.11	— .08	D 1135
Totals		27.81	26.96	26.88	26.25		
Averages		9.27	8.99	8.96	8.75	+ .21	
Grand Total and Averages.		192.87	185.67	116.51	115.47		
		9.21	8.85	5.55	5.50	+ .05	

J. A. V.

The Bindweed

By E. L. Caum

The California bindweed or morning-glory (*Convolvulus arvensis* Linn.) was first recorded from Hawaii in 1918, when plants were found on Maui and Oahu. Recently, the weed has come to the fore as a possible cane-field pest, and questions as to identification and methods of eradication have arisen.

Although by its common name accredited to California, the plant is probably a native of Europe, and is widely distributed throughout the temperate and subtropical regions of the world. California, however, is undoubtedly the immediate source of the weed in Hawaii, the seeds arriving thence in baled hay or stock feed of some kind. The bindweed is a vine, spreading chiefly by means of the long, creeping, cord-like roots, which may bud new plants at any part of their length. The stems are smooth, slender, twining and leafy, attaining a length of about three feet. The leaves range in length from one to three inches, and are shaped more or less like an arrow-head or spear-head, with two lobes at the base. The leaves vary considerably in shape, even on the same stem, ranging from obovate-hastate to broadly and bluntly triangular, and in some instances the basal lobes are not clearly differentiated. Somewhere on the plant, however, will be found leaves that plainly show the characteristic ear-like tabs. Fig. 1 shows the range of variation in leaf shape exhibited by this weed. The basal lobes will serve to distinguish the plant immediately from any of the other morning-glories that may occur in or along the edges of the cane fields, as these others all have leaves that are either clearly heart-shaped or digitate. The flowers are funnel-shaped, one inch or somewhat less in length and diameter, white or pinkish, occurring singly or in pairs, but occasionally three or four in a cluster. The small, roundish seed-pods are two- to four-seeded. The seeds are dull dark brown, coarsely roughened, oval, 3 to 4 mm. or about 1/6 of an inch long, one face convex, the other face sloping to the edges from a broad central ridge.

This European bindweed, together with the American species *C. sepium,* which thus far has not been reported from Hawaii, are most obnoxious weeds, in many parts of the country ranking among the worst of all the agricultural weed pests, and in some regions they are by far the worst. *Convolvulus arvensis,* fortunately the only one with which we are now concerned, is so destructive of crop plants when it occurs in cultivated fields and so difficult of eradication when it once becomes established that every effort should be made to extirpate the species before it becomes widely distributed throughout the agricultural lands of the Territory.

The outstanding injurious effects caused by the weed are: (1) It reduces crop yields. By growing with crop plants, the bindweed is in direct competition with them, and occupies space that is intended for the crop. The roots rob the crop plant of food and water while the stems, twining about and over any plant within reach, rob it of light and air. Under these conditions it is obvious that

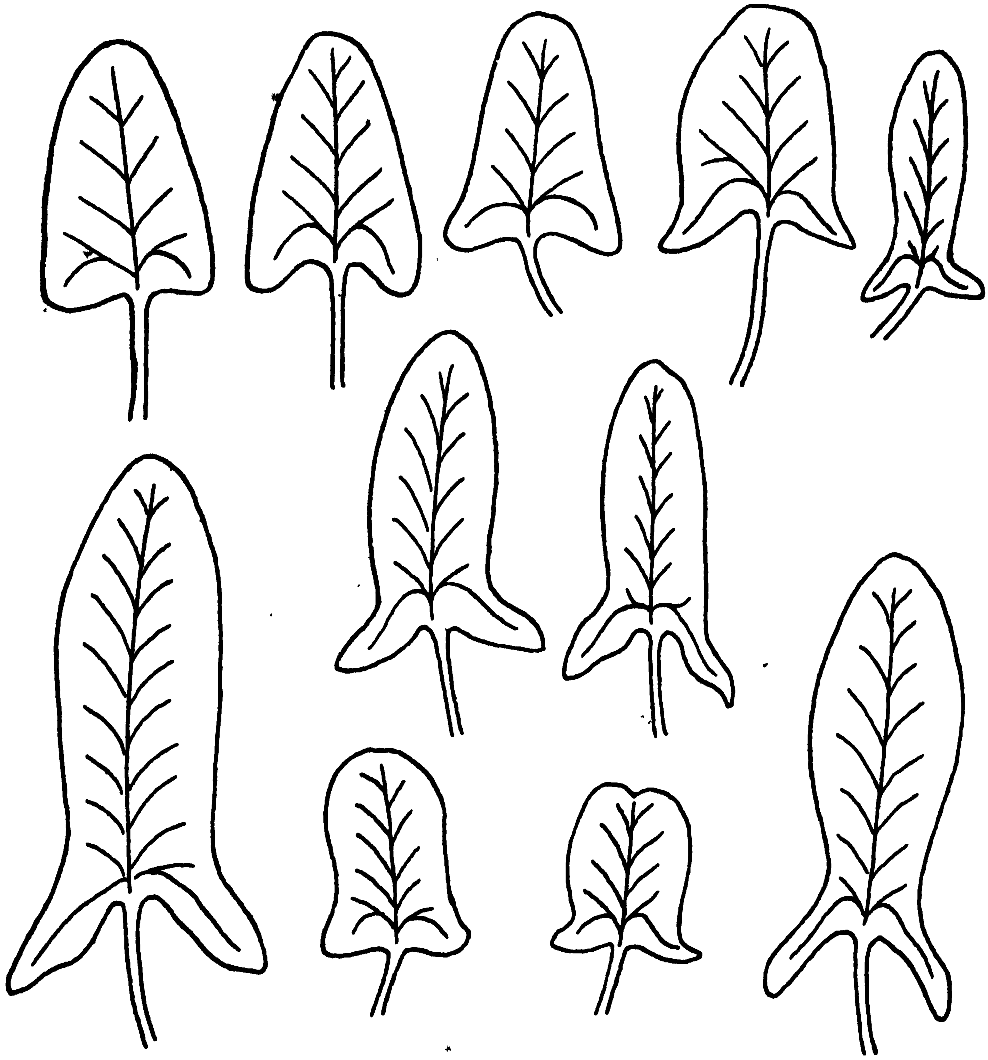


Fig. 1. Variation in the leaves of the Bindweed, drawn natural size from Hawaiian specimens.

reductions in crop yields are bound to result. Small plants such as vegetables cannot compete with the weed, and are soon completely choked out. Larger and taller plants such as corn, and by inference cane, can grow away from the weed if they are given a fair start, but otherwise they too will be dragged down and smothered by the rank growth of the vine, unless expensive and continuous hand cultivation is practiced. The ordinary machine cultivators are absolutely useless for keeping the bindweed in check. Corn fields where the weed is luxuriant, and where only the normal weed cultivation is given, will often show a complete loss. Even where the crop plant gets above the vine, there is still the loss of water and nutrients to be considered. With the continuous growing season that we have in Hawaii, it is easy to see that the weed might well do serious damage to young cane.

(2) It increases the amount of labor and the cost of field operations. Crop losses may be reduced by thorough tillage, and the reduction in crop thus partially

overcome by the greater amount of cultivation given. This, of course, increases the cost of the crop two ways, a greater cultivation cost for a smaller yield. In still another way the weed increases costs, since by twining around and over the crop plants it makes a dense tangle along the ground, increasing the labor involved in harvesting.

(3) It is a menace to near-by uninfected areas. This point is obvious, as the plant cannot be kept within bounds by ordinary methods, and each small patch is a center of infection for the surrounding territory.

(4) It reduces land values. This is a natural corollary of the points brought out above, and was strikingly illustrated a few years ago in Washington when, even during the time of high land values, individuals and companies engaged in selling and loaning money on land were glad to sell bindweed-infested fields for what they could get, and they refused to make any loans at all on such fields. One such individual made the statement that "If in bodies of from one to five acres, I would not consider the acreage covered of any value, as the cost to eliminate would be more than the worth of the land."

The bindweed is most difficult of eradication, and in this connection the following quotation, taken from Bulletin 42 (1899) of the Iowa Agricultural Experiment Station, may be of interest:

> Tempted by the lively appearance which I had often observed some banks to assume from being covered with the blossoms of this Convolvulus, I planted twelve feet of a bank in my garden, which was about four feet in height, with some roots of it; it was early in the spring and the season was remarkably dry, so that I scarcely expected to see them grow; but a wet season coming on, soon convinced me that my apprehensions were unnecessary, for they quickly covered the whole surface of the bank, to the almost total extirpation of every other plant. It being a generally received opinion, that if a plant was cut down close to the ground, it could thereby be destroyed, or at least, very much weakened, I was determined to try the validity of this opinion by an experiment, and accordingly, the whole of the Convolvulus was cut down somewhat below the surface of the ground. In about a month the bank was covered thicker than before. I then had recourse to a second cutting, and afterwards to a third; but all these were insufficient; for now at this present writing (August) the bank is wholly covered with it; nor do I expect to destroy it, but by leveling the bank and destroying the roots.

The bindweed spreads in three ways, by seeds, by lateral spreading, and by the transfer of root parts. The first of these methods, seed, is probably the least important, although this was undoubtedly the means by which the plant reached Hawaii. Under local conditions at least the plant seems to flower rather rarely and sparingly, although the vegetative growth is luxuriant. Such seeds as may mature can easily be carried to new areas embedded in mud adhering to the shoes of a person walking through a bindweed patch. The greatest danger in seed dispersal, however, is where the plant is permitted to grow along the banks of streams or irrigation ditches, where the water can easily distribute the seeds far and wide. The other two methods of distribution, lateral spreading and transfer of root parts, come about as a result of the great extent and the almost incredible vitality of the root system. The main roots, long and cord-like in character, penetrate the soil in all directions and to a great depth, frequently more than six feet. These roots,

particularly the uppermost portions near the surface, bear buds which send up new shoots, or adventitious buds may form at any part of their length, to give rise to either roots or shoots. For this reason a simple grubbing out of the plant is entirely insufficient, as the pieces of root left in the soil will form buds and give rise to new plants. Harrows, plows and similar machine cultivators are rather efficient distributors of the weed, as in passing through a bindweed patch they will break off pieces of the main roots which, in being dragged over and dropped in uninfested areas, will start growth and produce both roots and shoots, and thereby form new centers of infestation.

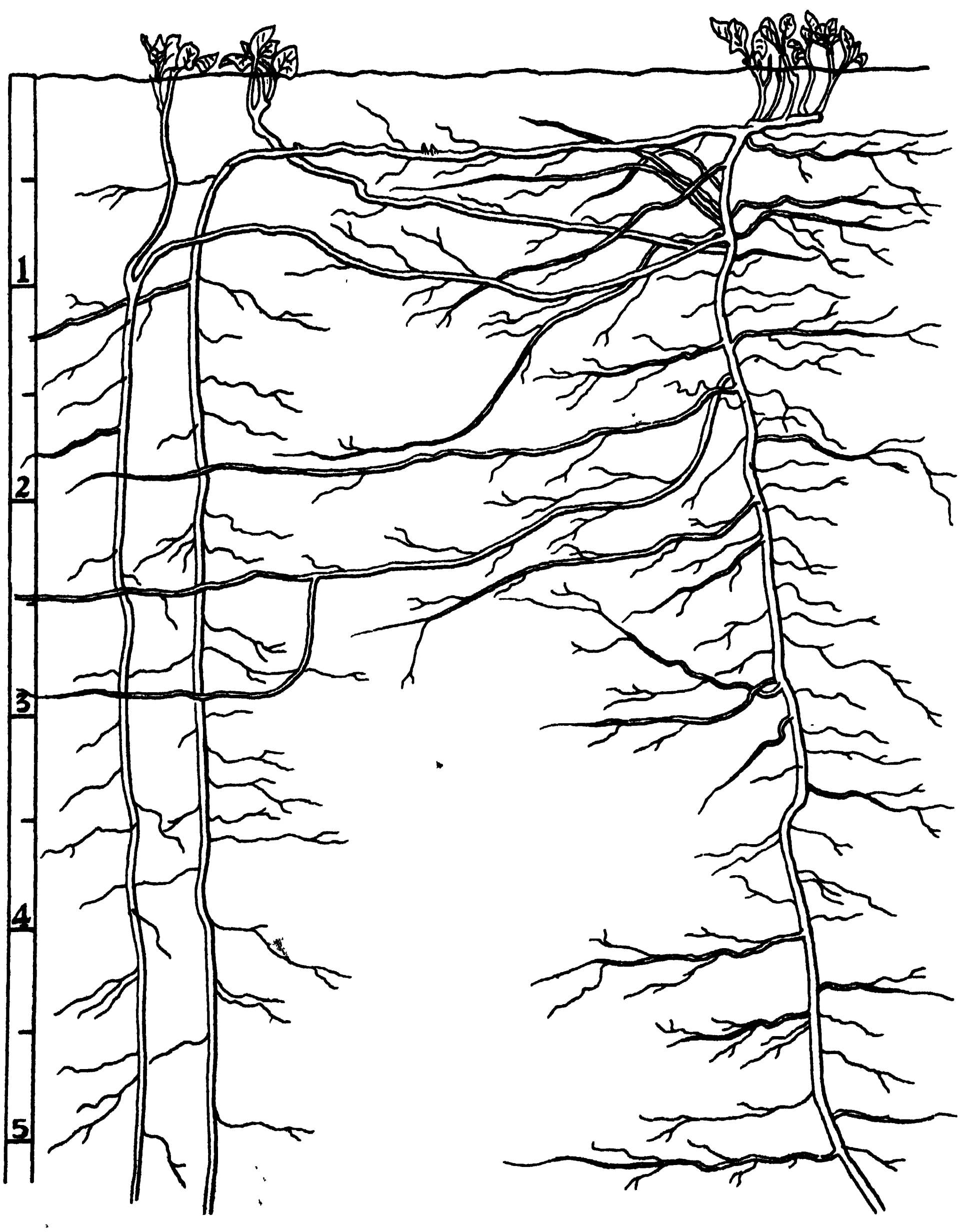


Fig. 2. The root system and budding habits of the Bindweed (after Schafer). The scale at the left is marked in feet.

Many methods of control of this weed pest have been tried, but very few have proven successful, and none of them is both cheap and speedy. Where it is feasible, one method that has been used with a measure of success is turning hogs into infested areas, after one or two thorough plowings to loosen the soil and bring the roots to the surface. These animals are very fond of both the tops and roots of the bindweed, and will in time eliminate it, if aided by an occasional plowing. Another method is to plant infested areas to alfalfa. This crop, if it can be well established before the weed gets too heavy, seems to resist the development of the bindweed, and the frequent cutting of the alfalfa or the utilization of the alfalfa patch for pasturage will keep the bindweed from seeding and will eventually starve it out. This, as may be judged, is a matter of years, although the weed is in no way injurious to animals, and has no detrimental effect on them when mixed with their fodder. The most successful way of eliminating the bindweed, however, and the one requiring the most care and attention, is clean cultivation, but this cultivation must be thorough and persistent. Hand hoeing that is not thorough and not sufficiently frequent will simply aggravate the trouble. If the top growth is kept continually cut off, no seeds can form and the roots will in time be starved out. To employ another quotation, "Nothing but persistent watching and the careful cutting off of all parts above the ground will eradicate this weed." Of course, in the absence of experiments along these lines in Hawaii, it is impossible to say how long a process this may be, but on the mainland it is said that going over the land once every week or ten days, during the entire growing season of the weed, which is between the spring and fall frosts, is required, and this treatment should accomplish the desired results in two years in most cases, and probably one year would suffice if the plants were not deeply rooted. By a year is meant a growing year, of course, not a calendar year, and Hawaii's twelve-month growing season, with the roots working steadily to produce top growth, should bring about their final exhaustion much sooner.

This practice of clean cultivation with hand implements is recommended primarily for areas of infestation in cultivated ground, where the fertility of the soil is of importance and must be preserved. The same effect, a continuous killing of the top growth, can be achieved by the use of a standard arsenical spray, but the sprayings must be frequent enough to knock down the green tops of the weed as soon as they appear. There is some danger in the use of this spray, however, as arsenic is known to have a stimulating effect on plant roots, and while it is satisfactory for use on succulent weeds where the death of the tops is followed quickly by the death of the roots, the results might be very different in the case of a weed with a root system as tenacious of life as is that of the bindweed. Various other chemical herbicides have been employed in experimental work, but most of those that are sufficiently strong to kill the weed have the disadvantage of either poisoning the soil or of being expensive, or both. Common salt is effective, but it must be applied at the rate of about one pound per square foot, and it has detrimental effects on the soil. Sodium chlorate in a 12.5 per cent solution was used successfully in Kansas, three treatments about two to three weeks apart being sufficient to eradicate the weed, but the after effects of the chemical are uncertain.

In the Kansas experiments it was claimed that there were no soil poisoning effects, but some experiments in Hawaii have shown a very decided adverse effect on cane growth, while other experiments have shown no noticeable effect at all. It might be dangerous to use sodium chlorate in fields of growing cane.

Naturally, the most efficient herbicides are the ones that destroy the roots of the weed, not limiting their action to simply burning off the top growth, and these are exactly the herbicides that cannot be used close to growing crops. They can, however, be used in fallowed fields prior to planting, or in places where the

Fig. 3. The California Morning-glory or Bindweed, showing habit of growth (after Criddle).

preservation of the soil fertility is of no importance. An effective spray of this sort is an emulsion of one part of Diesel oil with two parts of water, which is more effective than the Diesel oil alone. With many kinds of weeds this emulsion not only kills the tops but very quickly rots out the roots, and although we know of no experiments made with it on the bindweed, it has proven deadly to many other perennial weeds, and it has no residual effects. Along railroad tracks, in roadways and similar situations a half-and-half mixture of crude oil and kerosene may be used. It was this mixture that was used to wipe out the weed along the railroad right-of-way on Maui at the time of its first appearance in 1918. Other herbicides that act quickly and surely are carbon bisulphide and chloropicrin, but both of these are expensive, and the cost of application on large areas might be rather high. Chloropicrin in particular is certain death to any plant with which it comes in contact, has no poisoning effects on the soil, and could well be applied despite its cost should the Diesel oil emulsion prove ineffective. It is an open question whether high priced materials of this sort would really be high priced in the end. There is no doubt but that a single good application of chloropicrin will eradicate the weed, and the failure to eradicate it, followed by its establishment in the fields, would also prove expensive, as would continuous hand hoeing over a period of possibly a year. However, in dealing with an incipient weed pest having the potentialities of the bindweed there should be no false economy practiced.

To summarize: The California morning-glory or bindweed is known to have been in Hawaii for about fifteen years, and although in other places it is an agricultural pest of major importance, in Hawaii it has not as yet assumed that position. Judging by the losses caused by it in other parts of the country, its potentialities for damage to the agricultural industries of Hawaii are great. It is most tenacious of life and extremely difficult to eradicate. There is no proven method that is both cheap and speedy. An emulsion of one part of Diesel oil to two parts of water is highly effective when used on other perennial weeds, and has no detrimental effects on soil fertility. There seems to be no good reason why it should not prove equally effective on the bindweed. Failing this, chloropicrin is a swift and certain plant poison with no soil poisoning features, but it is expensive. If neither of these methods of eradication are feasible, the only other safe method is clean culture by thorough hand hoeing at intervals of a week or ten days, or as often as necessary to prevent the formation of top growth. Most herbicidal sprays are no more efficient than this hand hoeing, and some are less so. Where the preservation of the soil fertility is of no consequence, a half-and-half mixture of crude oil and kerosene has been shown to be effective.

A brief illustrated note on the occurrence and habits of the bindweed was published in the *Hawaiian Planter's Record*, Vol. XIX (1918), pp. 347-349, and more recently an illustrated discussion of the weed appeared in *Weeds of the Pineapple Fields of the Hawaiian Islands*, by St. John and Hosaka (*University of Hawaii Research Publication No. 6*, 1932), pp. 122-123.

Chromosomes of Sugar Cane

Translated literally the word chromosome means "color body." The term is appropriate because these small bodies are deeply stained when treated with certain dyes.

As everyone knows, each living cell, whether plant or animal, contains a nucleus, a more or less spherical mass of protoplasm which is denser than the surrounding material in the cell. During its resting stages this nucleus tends to have the appearance of a homogeneous mass. When the cell is making ready to divide, however, part of the nuclear material resolves itself into a number of small units of protoplasm. These are the chromosomes.

The number of chromosomes is definite and constant for each species. The chromosomes of many species of plants and of animals have been investigated by cytologists during recent years. The following list gives a few examples of the numbers found.

	Pairs of Chromosomes
Garden pea	7
Garden bean	8
Wheat	21
Tobacco	24
Dog	11
Cat	18
Man	24

It may be asked why we speak of "pairs" of chromosomes. The reason is obvious if we remember that each new individual results from the union of an egg cell formed by the mother and a spermatozoan (or pollen nucleus) supplied by the father. One member of each pair of chromosomes, then, is contributed by the mother and the other member of each pair by the father.

The chromosomes are believed to be the carriers of the "factors," or "genes," which determine heredity. Sugar cane seedlings, to cite a familiar case, differ from each other in many respects. Some are slender like Uba, others thick like Caledonia. Some are red like D 1135, others are yellow like Lahaina. Some are high in sucrose like Badila, others low like Kassoer. How do these differences come about? The present conception of the mechanism of heredity is that the traits of each individual are determined by the action and interaction of these "genes," or "factors," carried by the chromosomes.

The chromosome number in man, as has already been mentioned, is 24 pairs. Each living cell in the human body contains a nucleus, and each nucleus contains its 24 pairs of chromosomes.

When a cell divides to form two new cells each chromosome splits lengthwise with the result that each of the two new daughter cells receives its full complement of 24 pairs of chromosomes.

Fig. 1. Photomicrograph of the male and female organs of an H 109 cane flower. The male organs are comprised of three stamens with their reddish anthers, containing bags of yellow pollen. The female organ is comprised of the pistil with its two feathery purple stigmas and white ovary.

One might reasonably ask why it is that the human embryo resulting from the union of an egg cell and a spermatozoan does not contain twice as many chromosomes as either parent. In other words, if each cell in the bodies of both the father and the mother contains a nucleus composed of 24 pairs of chromosomes, is it not to be expected that the new individual resulting from a fusion of the male nucleus and female nucleus would have 48 pairs?

The explanation is simple and at the same time remarkable. As we have already seen, when an ordinary body cell divides to form two new cells, each chromosome splits lengthwise, and each daughter cell thus contains exactly as many chromosomes as the cell from which it was formed. However, when a cell in the ovary of the female or the testicle of the male divides to form an egg cell or a spermatozoan the chromosomes do not split lengthwise. Instead the two members of each pair of chromosomes part company and the resulting germ cell thus contains only one chromosome of each pair. This process, which results in reducing the number of chromosomes from 24 pairs in the body cells to 24 single chromosomes in the germ cells, is called the "reduction division." This mechanism of germ cell formation prevails throughout the plant and animal kingdoms.

The reduction division provides an opportunity for the reshuffling of chromosome combinations. Thus in man, some spermatozoa will be formed which contain all 24 of the chromosomes which the individual received from his father, and, consequently, none of those which he received from his mother. Other spermatozoa will contain 23 of the paternal and only one of the maternal chromosomes, still others 22 and 2, and so on. As a result, the individual produces many types of spermatozoa, some of which carry a preponderance of the chromosomes which he received from his father, others a preponderance of the chromosomes which he received from his mother, and still others in which the honors are equally divided.

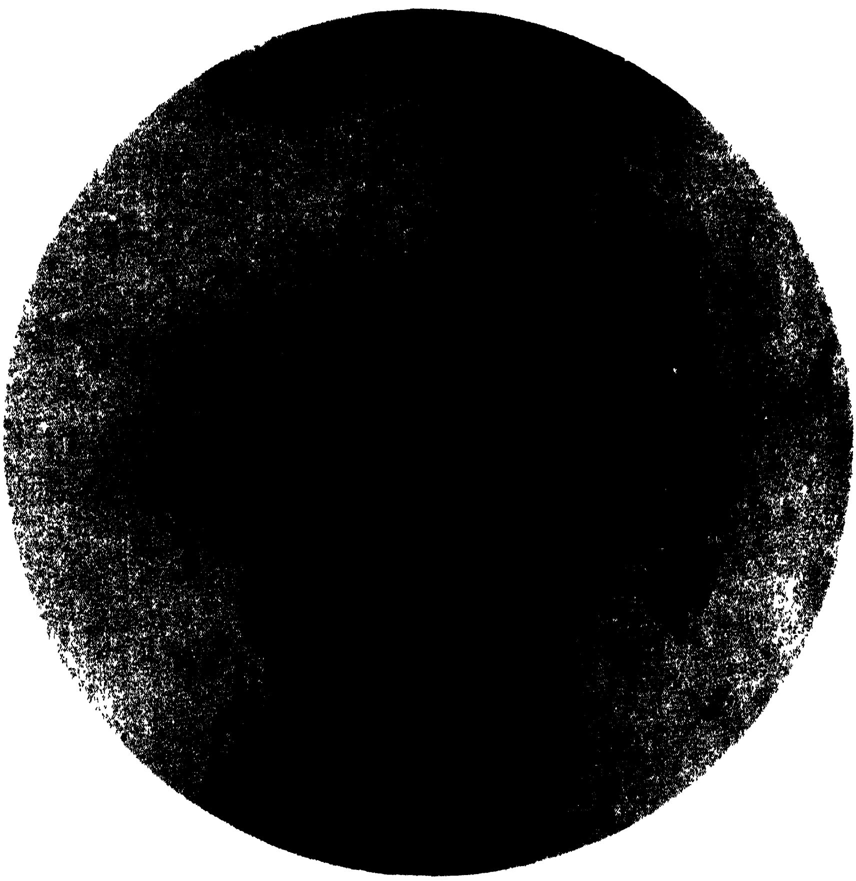


Fig. 2. Photomicrograph of chromosomes of H 109 cane. They are shown here in one of the cells found within the anther of the cane flower, which cell by dividing twice forms four pollen grains. In the nucleus of these cells, called "pollen mother cells" (microsporocytes), occur 40 pairs of chromosomes, and it is here that the so-called "reduction division" occurs, i.e., when these cells divide, one of each of the pairs of chromosomes is distributed to each of the two daughter cells. Thus, in pollen grains there are found only 40 chromosomes, while 80 are found in the vegetative cells of the plant, i.e., those cells found in the root tips, leaves, stalks, etc. × 1577.

For many years, Bremer (1, 2, 3, 4, 5, 6), the cytologist at the Pasoeroean Station, in Java, has been studying the chromosome relationships in the various species of sugar cane. He finds that the thick or "noble" canes, of which Lahaina is a typical example, have 40 pairs of chromosomes. The Uba group has 59 pairs, and the wild *Saccharum spontaneum* has 56 pairs.

Bremer reports an unusual phenomenon when the noble canes are pollinated by the wild *spontaneum* canes. The nucleus of the egg cell of a noble cane contains 40 chromosomes. The nucleus of the pollen grain of *spontaneum* contains 56 chromosomes. One would expect that when the two nuclei unite the resulting embryo would have 40 + 56 or 96 chromosomes. Actually the hybrids between the two species which Bremer has studied have 136 chromosomes.

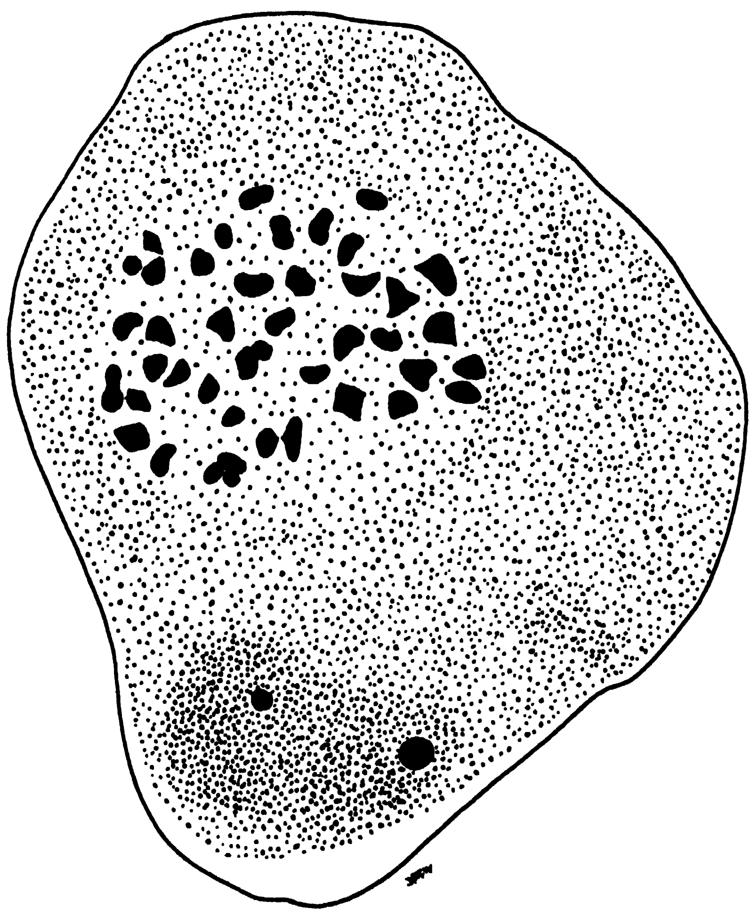


Fig. 3. The chromosomes of H 109 cane shown diagramatically. This drawing was made to scale by the aid of a camera lucida and shows the same cell as is pictured in Fig. 2. By the use of such drawings the chromosomes may be counted with less difficulty. × 2760.

Bremer advances the following explanation: When the egg nucleus of a noble cane unites with the pollen nucleus of a *spontaneum,* the chromosomes of the former are stimulated in such a way that they divide prematurely, so that instead of 40, the egg nucleus now contains 80 chromosomes. This nucleus, when it fuses with the pollen nucleus, produces an embryo which contains 80 + 56 or 136 chromosomes, the number actually observed.

As a result of the doubling of the chromosome number in the egg cell of the noble cane mother, the hybrid seedlings might be expected to show more of the noble cane characteristics and less of the *spontaneum* characteristics than would otherwise be the case. It is interesting that the hybrids between the two species do in fact bear a closer resemblance in stature to their noble cane mother than to their *spontaneum* father.

Fig. 4. Photomicrograph of chromosomes of H 109 cane. They are shown here in a cell of a root tip and are 80 in number, or just twice the number found in the pollen grains and egg cells in the flowers. In such vegetative cells the chromosomes are characterized by being the shape of small bent rods somewhat entwined together, while in the pollen mother cells they are shorter and thicker, being almost isodiametric clumps. × 2103.

The results of this finding of Bremer's may be cited as an example of the sort of information which cytological studies may bring to bear on breeding problems.

There is much still to be done in this field. Cytological work is exacting and time-consuming and progress is necessarily slow. It is to be hoped, however, that in the course of time our information on the chromosome relationships in the various cane species and their hybrids will be more complete than it is today.

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* These three citations are translated in Genetica, Vols. V, VI, VII, respectively.

D. M. W.
A. J. M.

Measuring Production in Terms of Temperature

By U. K. Das

It is generally admitted that the high level of production in these Islands is due to the application of scientific methods in our cane culture.

These methods consist of precise measurement and control of our resources and of the essential factors in production. We measure our land, we measure the amounts of seed and fertilizer that go into this land, we measure the man-days of work required to bring a crop to maturity, we measure the amount of water applied, and recently we have also begun to measure the factor of time as is evidenced by the increasing use of such terms as yields per acre per month.* But there are other essential factors in crop production besides soil, fertilizer, labor. water and time, namely, temperature and sunlight. It is, therefore, the logical sequence of the increasing application of science in our cane production that we should now turn our attention to measurement of temperature as an aid to future progress.

Temperature and Cane Growth

Before we proceed further let us see what we know about the effect of temperature on cane growth. Alexander (1), Stender (2), and others have shown by actual field measurements of cane growth that under conditions of abundant plant food and moisture the relation between temperature and cane growth is very marked indeed. (A figure from Stender's work is reproduced here below.) If the relationship is so pronounced, may it not be worth while to make an attempt to devise some means by which we can measure this temperature effect much the same as we would measure, let us say, the effect of irrigation water applied?

Measurement of Temperature Effects

It was De Candolle, the famous botanist, who pointed out many years ago that below a certain temperature plants could not grow and that effective warmth must be reckoned as "accumulated temperature" above this minimum point. At the instance of Sir John Lawes and Sir Henry Gilbert, of Rothamsted, the British meteorological authorities began to issue their statistics of warmth in relation to agriculture as accumulated temperature.

This accumulated temperature is obtained by taking the effective temperatures above the selected zero point and summing them up for the number of days a crop has been in the field.

* The Experiment Station, H. S. P. A., drew attention to the value of this "per acre per month" conception. (Annual Report, Experiment Station, H. S. P. A., 1918, p. 7.)

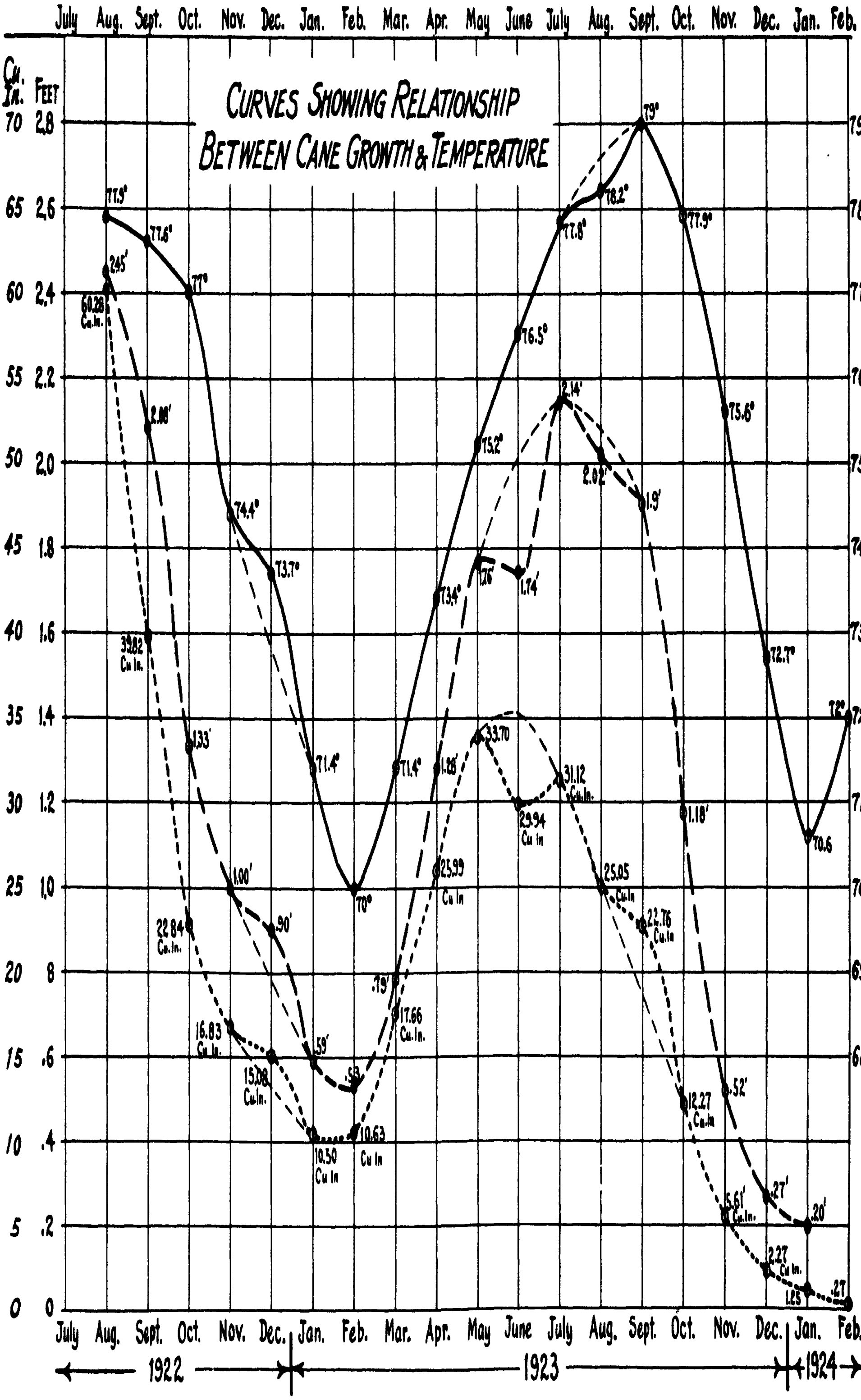
CURVES SHOWING RELATIONSHIP
BETWEEN CANE GROWTH & TEMPERATURE
July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb.
Cu. In.
Feet
Temperature
1922
1923
1924

Fig. 1

Smith (3) states that besides this process of summing up temperature, known as the "remainder" indices, there are two other methods known respectively as "the exponential" and the "physiological summation" indices.* We shall not go into a detailed discussion of the relative merits of all these processes; suffice to say that they all have their good and weak points and none of them alone can explain all the facts concerning the growth and yield of a crop.

Zero Point of Cane Growth

Most of the work with the summation processes has been done on subtropical crops and 42° F. has been usually taken as the zero point. But sugar cane is of tropical habitat and we know that it hardly makes any growth in winter in Louisiana or in the Punjab, India, where the mean winter temperature is about 55° F. We also know from actual measurements of cane growth as reported by Stender (2), Verret and Das (4), and others, that cane growth falls off very rapidly and becomes negligible below a mean temperature of 65°. From these considerations we feel justified in taking 60° F. as our zero point. In this we are not alone. Kincer (5) suggested that this zero point should be 55° F. for corn and 60-62° F. for cotton. Very recently Magoon and Culpepper (6) have published a detailed investigation into the zero point of effective temperature for corn, and these authors have come to the conclusion that this varies between 50 to 65°, depending on the variety of corn. (We may also find the zero point to be different in the different varieties of cane. Not enough data are available at present to test this point.)

* The exponential indices are based on the application of Van 't Hoff's Law—namely, the velocity of chemical reaction is doubled with every 18° F. rise of temperature. The physiological summation indices are similar to those suggested by Livingston (14) from a study of the data obtained by Lehenbauer with maize seedlings. The indices are derived from actual length growth recorded at different temperatures.

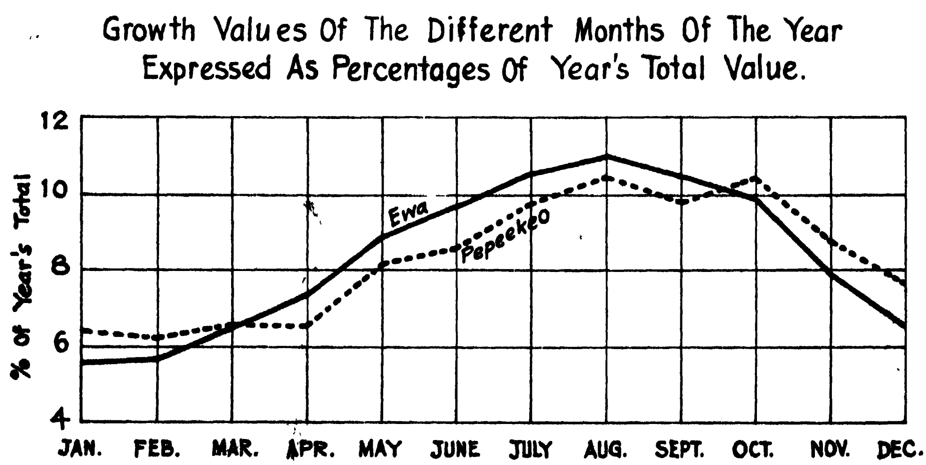

Fig. 2

Mean or Maximum Temperature as the Zero Point

The mean temperature is usually taken as the zero point. As we know, this mean temperature is obtained for each day by adding together and then dividing by two the maximum and the minimum temperature. Two places can have widely differing maximum and minimum temperatures yet they may have the same mean temperature. Thus a mean temperature of 70° F. may be obtained from a maximum of 80° F. and a minimum of 60° F. or a maximum of 100° F. and a minimum of 40° F.

Now, mean maximum temperature is usually an index of conditions by day and mean minimum of conditions by night. We also know that distinct life processes are carried on by a plant during the daylight hours and during the night. Surely, then, two places having the same mean but widely differing maximum and minimum temperature will not exert the same influence on plant growth. It is, therefore, evident that use of mean temperature may be wholly unsatisfactory as a base for obtaining total warmth or accumulated degrees, especially so when the resulting information is to be used for comparing one locality with another.* There is another good reason why we should prefer to use maximum temperature instead of the mean temperature. Seeley (7) has shown that what effects plant growth is not the air temperature but the actual leaf temperature, which is considerably modified by the conditions of the day—sunshine, clouds, etc. Maximum temperature may, therefore, be a closer approximation to plant temperature than the mean.

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* To illustrate the point—Waimanalo (Oahu) has an annual average maximum temperature of 81.7 and an annual minimum of 68.9°. Adding the two figures, and dividing by two we get 75.3° as the annual mean temperature of Waimanalo. The annual maximum for Ewa, Waipahu, and Waialua, is 83°, 82.5°, and 82.6°, and the minimum 64.6°, 65.9°, and 63.7°, respectively. The mean temperatures of these places are then 73.8°, 74.2°, and 73.2°. Taking mean temperatures only we would say that Waimanalo has the best temperature climate. But all of us know that cane does not yield as well in Waimanalo as in the other three places mentioned. In fact, from physiological considerations we would expect Ewa and the other two places to be more favorably placed. For it has been recorded with other crops that, at least in the case of the adult plant, assimilation of dry matter (sugar in our case) is favorably influenced by a high day temperature and a comparatively low night temperature. High day temperature (an index of which is maximum temperature) favors assimilation rate while low night temperature (an index of which is minimum temperature) prevents excessive loss by respiration. Lundegardh (9) has shown that with equal day temperature a raising of night temperature by 10° C. causes an increase in loss by respiration of as high as 30 per cent of dry matter in a field of potatoes. The presence of this positive correlation of yield with maximum temperature and negative correlation with minimum temperature was actually demonstrated in a previous statistical study (10) of the Ewa Plantation Company.

It must, however, be added that as long as the study and the information obtained are confined to one plantation only, mean temperature may provide just as good a zero point as the maximum temperature. In fact our previous study (11) of the Pepeekeo Sugar Company has shown that mean temperature provides a satisfactory base for calculating total warmth.

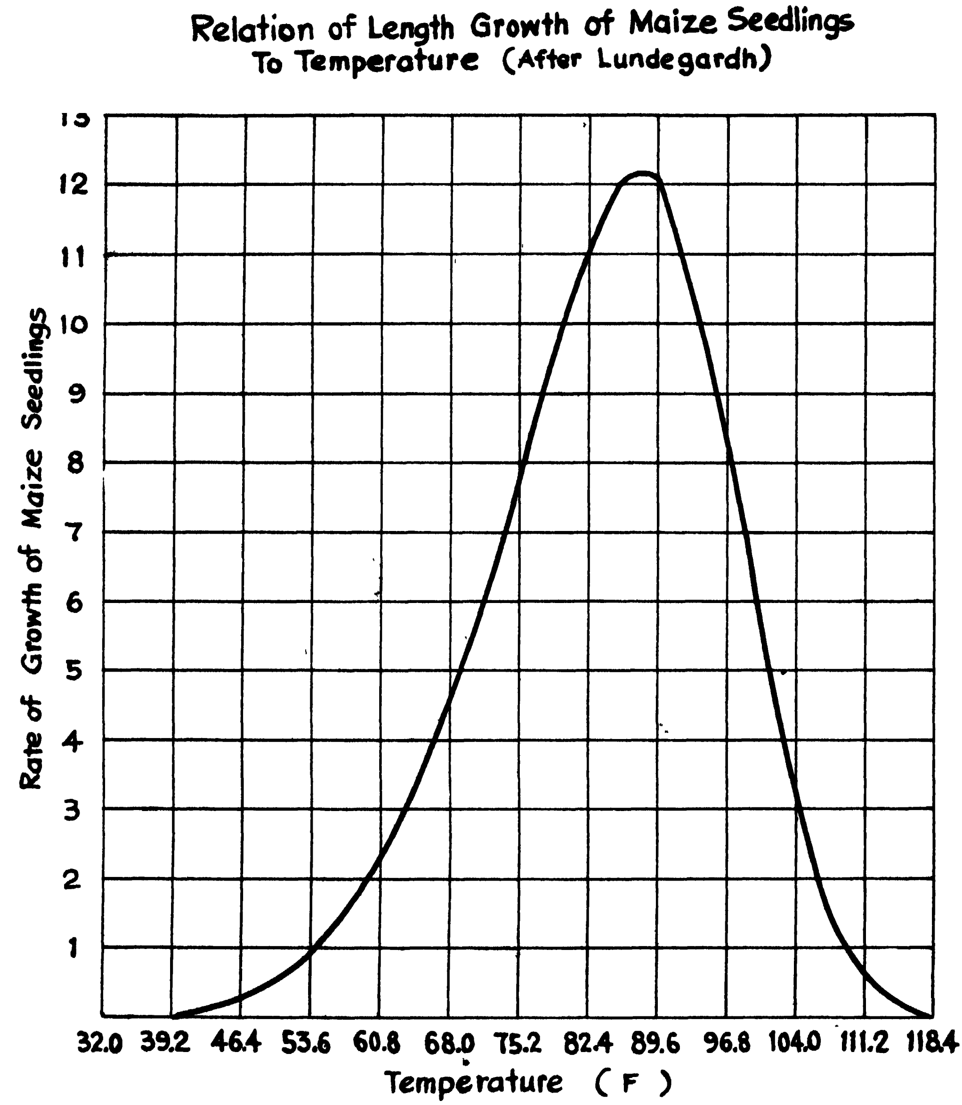

Fig. 3

DAY DEGREES—OR EFFECTIVE TEMPERATURE FOR CANE GROWTH

If 60° F. of mean temperature should be the zero point of cane growth, as argued previously in this report, what should it be in terms of maximum temperature? The plantation weather stations of these Islands show a difference of 14 to 20° between the average minimum and the average maximum temperature. By taking half of this difference and adding to the zero point of mean temperature we get our new zero point of maximum temperature which is 67° to 70°. For the sake of simplicity we shall take 70° F. of average maximum temperature as the new zero point. A day-degree will then be defined as one 1° F. above 70° of maximum temperature for one day. To obtain the total or accumulated day degrees for one month, we may either add the day degrees for each

day or we may simply multiply the average maximum temperature of the month by the number of days in the month.*

Growth Values of Different Months in Terms of Effective Temperature

Several years ago Agee (8) called our attention to the advantage and necessity of evaluating the growing powers of different months of the year. From cane growth data and from considerations primarily of the hours of daylight, he derived growth values for each month of the year. In the case of Honolulu, the month of July was found to have anywhere from 3 to 5 times as much value as the month of January or February.

Let us now deduce these values from considerations of temperature alone. In Table I we take the temperature data of the Ewa Plantation Company and calculate the day-degrees normally received from month to month (normal temperature is the average of 26 years of data—from 1905 to 1931). Assuming the yearly total of day-degrees to be 100, we now calculate the percentage of day-degrees in each month of the year. Table I shows that at Ewa, 11 per cent of the year's total of day-degrees is in the month of August and only 5.6 per cent in January. In other words, if cane growth was proportionally influenced by temperature in the two months, we should expect to find twice as much growth in August as in January. The earlier work of Alexander (1) and more recent work do actually show that this ratio of 2 to 1 between August and January growth at Ewa is not far from the truth.

Similar values are worked out in Table I, for Pepeekeo Sugar Company. The monthly values for both Ewa and Pepeekeo as shown in Fig. 2, bring out interesting differences between the two places. From temperature standpoint, the fall months of Pepeekeo appear to be more important than those at Ewa, while in the latter case the spring months are the more important. This fact should deserve some consideration in the agricultural practices of the two places.

Differential Effects of Temperature at Higher Ranges

In the foregoing calculation, we have assumed that one degree of temperature between 70° F. and 71° F. is as effective as one degree between 80° F. and 81° F. This is contrary to the experience of plant physiologists, who find that temperature effects are different in the different ranges. How complex these effects are will be seen in the following graph (Fig. 3), reproduced from an article by Blackman (13). It shows the rate of length growth in maize seedlings at various temperature levels. We see that the rate of growth between 60° and 70°, for instance, is not the same as between 70° and 80° or 80° and 90°. There is no single law

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* After the temperature has passed beyond a certain point, it may be harmful to growth rather than helpful. This maximum point varies with the kind of plant and to a certain extent with other environmental factors. In the case of sugar cane we have reasons to believe that the maximum point is seldom, if ever, reached in the plantations of these islands. The highest average maximum temperature for a month recorded in any of the plantation is 90° F. Louisiana exceeds this temperature in the summer months and we know that in Louisiana it is the summer months that produce growth. The average maximum temperature for the spring and winter months of Pasoeroean (Java) is 89° F. and Pasoeroean is one of the most productive sugar cane regions in Java.

or a simple formula that can completely describe this differential growth rate, which varies not only with temperature, but also with the kind of plant, or the kind of function of the plant. It is known, however, that the Van't Hoff principle—the velocity of reaction doubles itself with every 18° F. rise of temperature—applies to plant growth to a limited extent.* Assuming this law to be valid within the rather narrow range of seasonal differences in temperature obtained in these Islands, we may recalculate the growth values of the different months at Ewa. (See Technical Appendix—A.)

The new values are shown in Table II and Fig. 4. In comparing these new values with those given in Table I, we note that August has increased in value from 11 per cent to 12.1 per cent of the year's total, and January has decreased from 5.6 per cent to 4.7 per cent. For comparison, some values suggested by Agee (8) are also given in Table II. There is a surprising agreement between these values and the values originally obtained by Agee from consideration of daylight hours. But, whereas Agee's data would place the highest value on the month of July, the new curve shows August to have the highest value under Ewa conditions. Actual growth measurements taken in Honolulu do indeed show that under normal conditions we obtain more growth in August than in any other month of the year.

Growth Values of Different Months—Their Relation to Crop Cycles

The fact that no two months are alike in their capacity to produce growth is one that must be reckoned with in our crop schedules and agricultural practice. Agee (8) has pointed out in his original paper that, depending on the season of starting, a crop 18 months old may actually produce as much as one 20 or 22 months old.

* Lundegardh (9) states that the Van't Hoff law applies to plant growth only within a very limited range.

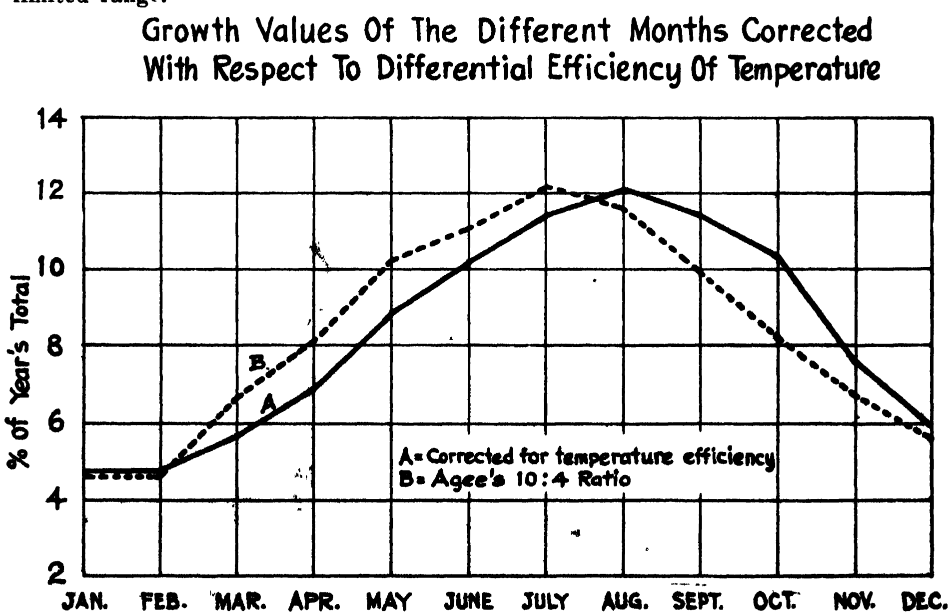

Fig. 4

Without going into a detailed discussion of the bearing of these different growth values on our cropping scheme, we may submit that most economic use of time and resources can only be made by taking into account the existence of such well established differences.

Accumulated Day Degrees (Total Warmth) and Yield

Having shown the usefulness of this conception of day-degrees to the evaluation of the growth values of the different months of the year, we may now proceed to evaluate yield in terms of actual warmth received. To start with let us take the comparatively simple case of the Pepeekeo Sugar Company. Here we have yield data for the past 22 years comparatively little affected by changes of cane variety, soil, crop length or management. These yield data should, therefore, provide a test for the applicability of day-degrees to crop performance.

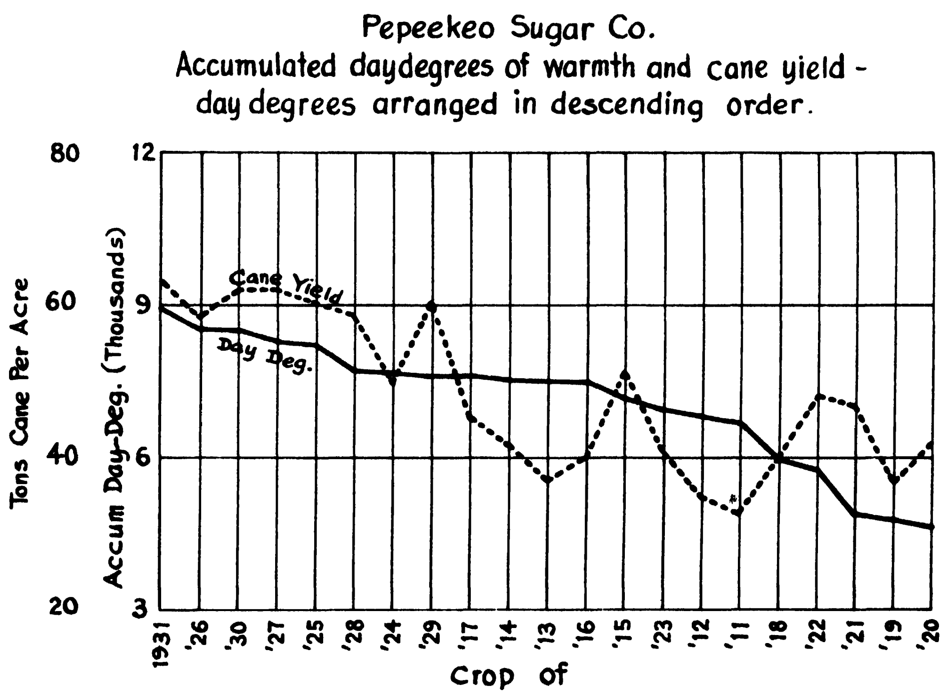

Fig. 5

At Pepeekeo long cropping has been and still is the general rule. We may then assume, for the sake of simplicity, a crop length of 24 months. We may also assume that July 1 is the average date of starting, that is by July 1, about half the area has been started. Now, from records of temperature, we may calculate for each of the past crops the total warmth or accumulated day-degrees actually obtained. In Table III and Fig. 5 are shown the cane yields per acre from 1911 to 1931 and the corresponding total warmth so calculated. In Fig. 6 the same data are presented as smoothed out curves to eliminate minor fluctuations and emphasize the trends only.

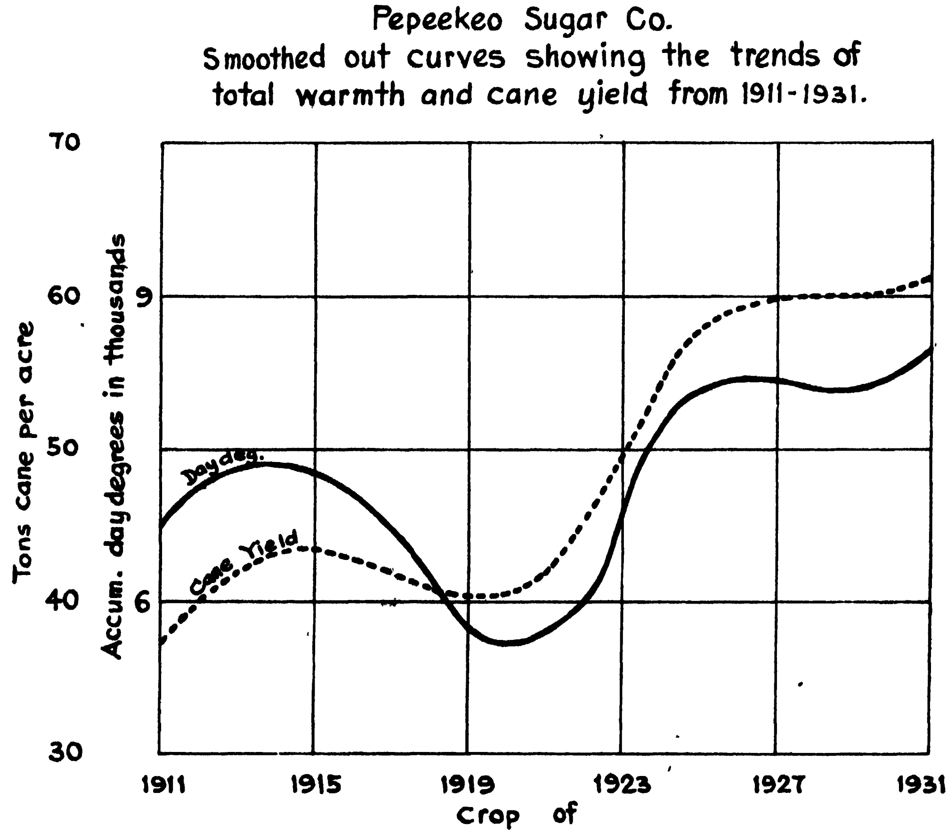

Fig. 6

The relation between total warmth and cane yield is very striking. It is the more remarkable considering that rainfall, which must be a factor in an unirrigated place like Pepeekeo, is not taken into account at all. Neither have we tried to correct for differential effect of temperature at diffrent levels or for cultural differences which are inevitably present from year to year.

From Pepeekeo, we pass on to the complicated case of the partly irrigated plantation—Honokaa Sugar Company. Table IV and Fig. 7 show the yield of cane and total warmth. The correspondence between the two is again striking. In all these years, Honokaa has passed through many varietal and cultural changes, but even so, temperature remains as the supreme influence.

One of the main reasons why temperature appears to control yield to such an extent in these Islands may be that in this subtropical climate a tropical, warmth-loving plant like the sugar cane does not generally obtain all the warmth it needs. Total warmth thus becomes a determining influence.

For want of satisfactory data, it has not yet been possible to study in detail this total warmth and yield relationship in any of our warmer plantations; but fragmentary evidence from the yield records of the Ewa Plantation Company tends to confirm our belief that even there, the above relation between total warmth and yield would generally hold true. (Also see Appendix—B.)

A Suggested Method of Utilizing Day Degrees for Estimating the Conditions of Current Crops

In the preceding pages an attempt has been made to measure the potential growth value of the different months of the normal year in terms of the average monthly maximum temperature of the place. It has also been suggested that these values can be used to estimate the potential yield value of crops of various lengths started at different times of the year.

A little thought will show that though these growth values are excellent for a general understanding and study of cropping schemes, they are far from satisfactory in evaluating the growth possibilities of current months for the simple reason that these months may be far from normal. To take an instance—the month of December, 1932, was 3° warmer in Honolulu than the previous December. In fact, the 1932 December was as warm as a normal spring month. Surely we would not want to take the growth value of a normal December to evaluate the growth of 1932 December.

This is just where the day-degrees come to our rescue. Why take the growth values obtained from consideration of day-degrees of a normal year? Why not take the day-degrees of this year, this month?

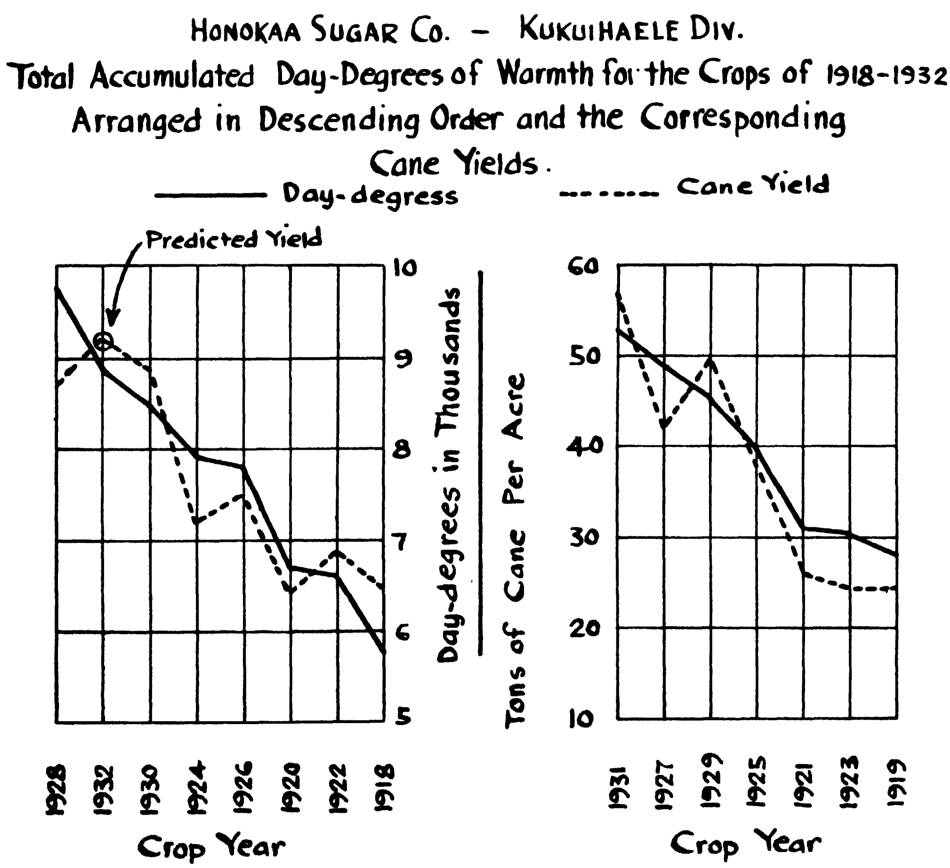

Fig. 7

Hereunder we suggest a scheme of summating the day-degrees for any crop from month to month which seems to offer attractive possibilities for measuring the progress of current crops. This method may be utilized for comparing the "condition to date" of one crop with another.

First, we determine the time of starting of the crop. Then referring to the temperature records, we obtain the actual day-degrees for the first month after starting. To this we go on adding progressively the actual day-degrees of each successive month to the time of harvest. In Table V and Fig. 8 we show the results obtained in this manner for two crops of the Honokaa Sugar Company, namely, the crop of 1920 and 1928. The month-to-month progress of temperature leaves no doubt in one's mind as to the advantage of the 1928 crop over the earlier one. The actual yield of 1928 was indeed very much higher than that of 1920. Similar charts drawn for a few other plantations tell the same story.

We are accustomed to chart the progress of field operations—irrigation, rainfall, fertilization, etc., of different crops for the purpose of comparison and agricultural control. Would not similar charts of the progress of temperature from month to month be of value in comparing one crop with another and in estimating their yield possibilities?

Discussion of the Methods—Their Drawbacks and Good Points

It is not denied that the methods herein suggested are far from perfect. The complex process of plant life—whose integrated expression total yield is—cannot be foretold or measured completely from considerations of temperature alone. There are other factors which must be reckoned with (but at the same time it must be admitted that where other factors remain more or less consant we should find growth and yield markedly influenced by the warmth received).

Herein we have considered only the average maximum temperature, but our previous study (10) has shown that minimum temperature is also a factor of importance. The fact that this minimum is so often correlated with maximum temperature probably explains the success of our efforts in evaluating the yield and temperature relationship of the Pepeekeo and the Honokaa Sugar companies.*

Besides the inter-relation and inter-dependence of temperature and other factors that concern growth, we have conditions within the plant that must also be considered. Can we assume for instance, that the same number of day-degrees will produce equal growth when the cane is six months old and when it is fifteen months old? In other words, should we not introduce a correction for differential rate of growth at various ages? Then there is the complicated factor of different plant processes each of which probably has a different optimum temperature.

But these obvious defects are inherent in all our agricultural measurements. We express yields in terms of acres, compare one field, one plantation with another on the basis of these figures. Can we say that one acre here is exactly

* **Probably, soil temperature should also be considered. However, we know very little as yet concerning soil temperature of a cane field.**

the same as one acre there? Are not we assuming that the other factors are constant? We measure yield in terms of pounds of plant food applied, in terms of gallons of irrigation water given to a crop; are any of these measurements, we submit, any more precise than the new measurements suggested in this paper? But none of us doubts the value of the accepted measurements in aiding our progress even though these measurements are far from perfect. In case of temperature we may at least say that it appears to influence yield to a greater degree than any other single factor we know of. (The factor of sunlight is associated with temperature.)

Heretofore, we have spoken of weather in a vague way. But here is at least one method by which we can express the temperature aspect of our weather in a

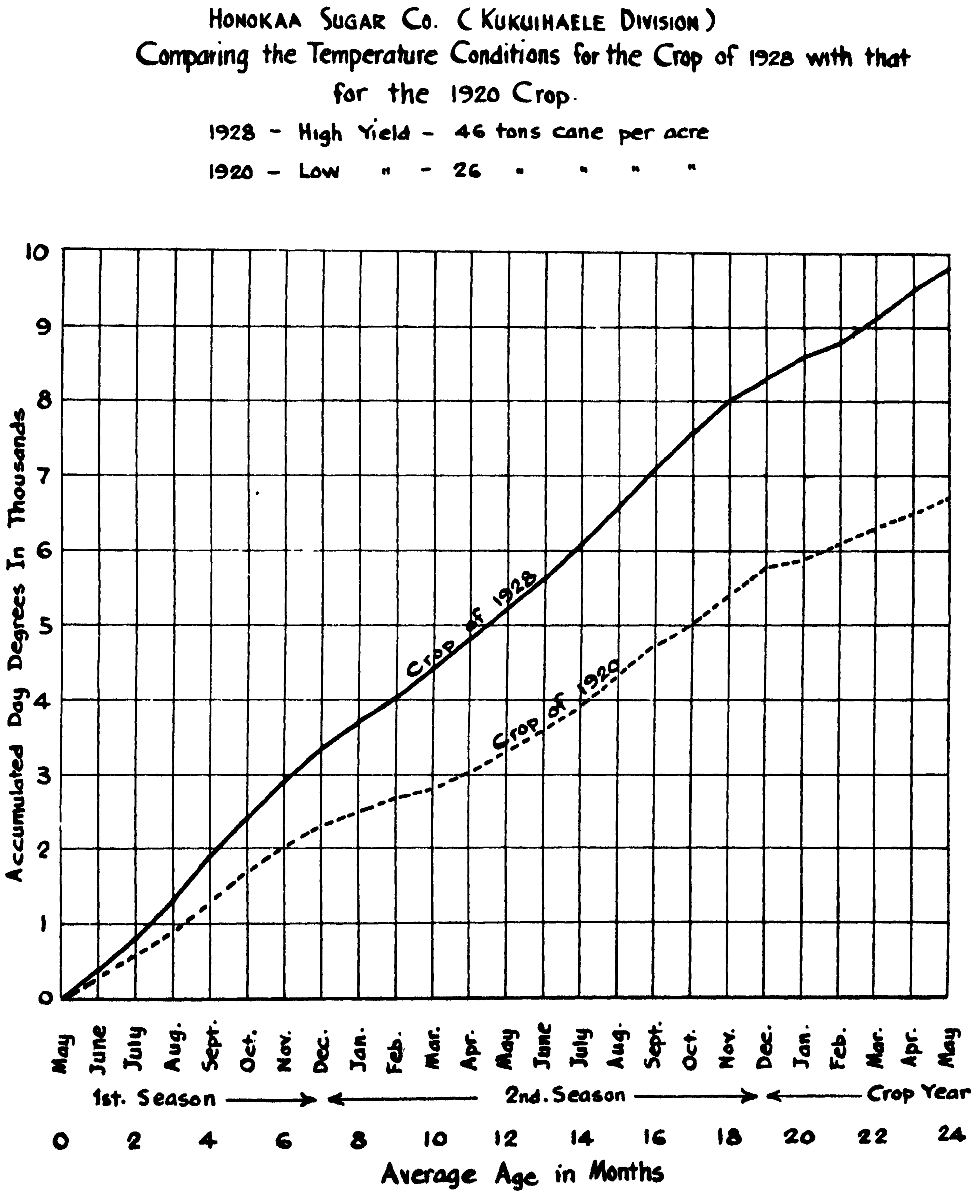

Fig. 8

quantitative manner. Heretofore, we have compared one plantation with another on the basis of soil, variety and other factors, but now we shall be in a position to compare them on the basis of climate.

However, in comparing one plantation with another or for that matter two widely separated fields of the same plantation, we will have to make sure that the temperature data are really representative of the conditions we are comparing.

It is possible that by bringing in other corrections (some of which are mentioned in this paper) an expression could be devised which might show an even better concordance with yield figures, but the complexity of the expression will probably hamper its wide use. The measurements here suggested are simple and the basic data are simply and inexpensively obtained.

SUMMARY

In the foregoing pages, a method is suggested of evaluating warmth quantitatively in terms of day-degrees. A day-degree has been defined as one degree (F.°) temperature above an average maximum temperature of 70°. It has been shown that the potential growth values of the different months of the year can be approximately evaluated by the use of this conception of a day-degree. It has also been shown that there exists a close relation between cane yield per acre of a plantation and the total effective warmth received. A method has also been offered by which one can evaluate the crop conditions to date from the point of view of warmth.

The shortcomings and the advantages of these conceptions and methods are pointed out. It is, however, hoped that the present methods can be improved as more experience is gained from their use. But the present imperfections must not make us forget the fact that progress in science generally proceeds from first approximations to exactness, from imperfections to perfections; that even an approximate measure of one of our important resources is far better than none at all.

TABLE I

CALCULATION OF GROWTH VALUES FROM TEMPERATURE DATA

Month	EWA PLANTATION COMPANY				PEPEEKEO SUGAR COMPANY			
	Mean Max. Temp.	Avg. Day-degrees	Day-degree x No. of Days	% of Year's Total	Mean Max. Temp.	Avg. Day-degrees	Day-degree x No. of Days	% of Year's Total
January	78.6	8.6	267	5.6	77.5	7.5	233	6.5
February	79.6	9.6	269	5.7	78.0	8.0	224	6.3
March	79.9	9.9	307	6.5	77.6	7.6	236	6.6
April	81.6	11.6	348	7.3	77.9	7.9	237	6.6
May	83.7	13.7	425	8.3	79.4	9.4	291	8.2
June	85.3	15.3	459	9.7	80.2	10.2	306	8.6
July	86.2	16.2	502	10.6	81.3	11.3	350	9.8
August	86.8	16.8	521	11.0	81.9	11.9	369	10.4
September	86.6	16.6	498	10.5	81.8	11.8	354	9.9
October	85.2	15.2	471	9.9	82.0	12.0	372	10.4
November	82.5	12.5	375	7.9	80.6	10.6	318	8.9
December	80.2	10.2	316	6.6	78.9	8.9	276	7.7
Total			4758				3566	

TABLE II

GROWTH VALUES CORRECTED BY APPLYING VAN'T HOFF'S LAW OF $Q_{10}=2$

Month	Mean Max. Temp.	Avg. Day-degrees	Correlated Values When August=100	% of Year's Total	Monthly % from Agee's 10:4 Ratio
January	78.6	8.6	39	4.7	4.7
February	79.6	9.6	39	4.7	4.7
March	79.9	9.9	47	5.7	6.7
April	81.6	11.6	57	6.9	8.1
May	83.7	13.7	74	8.9	10.3
June	85.3	15.3	84	10.2	11.1
July	86.2	16.2	95	11.5	12.2
August	86.8	16.8	100	12.1	11.7
September	86.6	16.6	95	11.5	10.0
October	85.2	15.2	86	10.4	8.3
November	82.5	12.5	63	7.6	6.7
December	80.2	10.2	49	5.9	5 6

TABLE III

PEPEEKEO SUGAR COMPANY
CANE YIELD PER ACRE AND TOTAL WARMTH

Crop of	Tons Cane per Acre	Accumulated Day-degrees	Order of Accumulated Day-degrees
1911	32.95	6711	16
1912	34.61	6765	15
1913	36.57	7554	11
1914	41.46	7582	10
1915	51.03	7202	13
1916	40.40	7532	12
1917	45.40	7654	9
1918	39.96	6026	17
1919	37.09	4769	20
1920	42.09	4744	21
1921	47.02	4915	19
1922	47.92	5821	18
1923	41.29	6988	14
1924	50.12	7718	7
1925	60.37	8156	5
1926	58.69	8580	2
1927	61.62	8243	4
1928	59.19	7725	6
1929	60.21	7681	8
1930	61.77	8464	3
1931	63.20	8902	1

TABLE IV
HONOKAA SUGAR COMPANY
(Kukuihaele Division)
CANE YIELD AND ACCUMULATED DAY-DEGREES

Crop of	Cane Yield	Accumulated Day-degrees
1918	24.8	5721
1919	24.6	6888
1920	23.5	6738
1921	26.3	7083
1922	28.9	6559
1923	24.5	7034
1924	31.5	7962
1925	38.0	7965
1926	35.0	7800
1927	41.5	8908
1928	47.0	9820
1930	49.0	8533
1929	49.7	8551
1931	57.7	9307

TABLE V
HONOKAA SUGAR COMPANY
(Kukuihaele Division)
MONTH TO MONTH PROGRESS OF ACCUMULATED WARMTH FOR THE CROPS OF 1928 AND 1920

	Crop 1928	Crop 1920
1st Season:		
May	384	251
June	828	551
July	1336	883
August	1860	1264
September	2355	1660
October	2876	2035
November	3305	2338
December	3674	2518
2nd Season:		
January	4024	2673
February	4416	2841
March	4835	3039
April	5216	3285
May	5638	3561
June	6091	3897
July	6593	4272
August	7123	4653
September	7591	5022
October	8003	5419
November	8321	5758
December	8569	5885
Crop Year:		
January	8842	6074
February	9097	6287
March	9469	6513
April	9820	6738

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TECHNICAL APPENDIX A

Quantitative relation between temperature and growth. Is it linear or non-linear?

In the body of the report it has been stated that actual measurements of cane growth lead us to believe that there exists a definite quantitative relationship between maximum temperature above 70° and cane elongation. In this report this relationship has been assumed to be linear, though it has been admitted that probably the true relationship would be more correctly expressed by a curve derived from other theoretical considerations—such as the application of Van't Hoff's Law. The following is a fuller discussion of the subject than that attempted in the main body of the report.

Here are some data on cane growth obtained in a test at the Experiment Station, H. S. P. A., Honolulu, in 1926. The cane was given optimum fertilization and irrigation, so that these two factors could not be limiting. The average elongation of 100 to 200 stalks of different ages was recorded every two weeks.

TABLE I

Average Elongation in Feet	Mean Maximum Temperature	Average Elongation for a 10-Day Period
0.49	80.1	0.35
.32	77.4	.23
.48	81.1	.34
.74	83.4	.53
.80	83.3	.57
.81	83.7	.58
.80	83.4	.57
.93	85.6	.67
Average..............	82.25	.48

In Fig. 9 the average daily elongation is plotted against temperature, and the line of best fit determined mathematically. (An inspection of the data will show that the recorded elongation indicates a linear relationship with temperature.) The equation for the line is:

$$y = 0.48 + 0.0558\ (t - 82.25)$$

Where y = elongation in feet for a 10-day period
t = mean maximum temperature for the period

The equation shows that y = 0, when t = 73.65. In other words the present data would indicate the zero point of elongation to be as high as 73.65°, assuming the relation to be linear beyond the range of temperature obtained in this experiment. But it will be noticed that we have no actual elongation data for temperature below 77° maximum. Therefore, we cannot be certain that the elongation would really fall off so rapidly below 77° as to become zero at 73.65°.

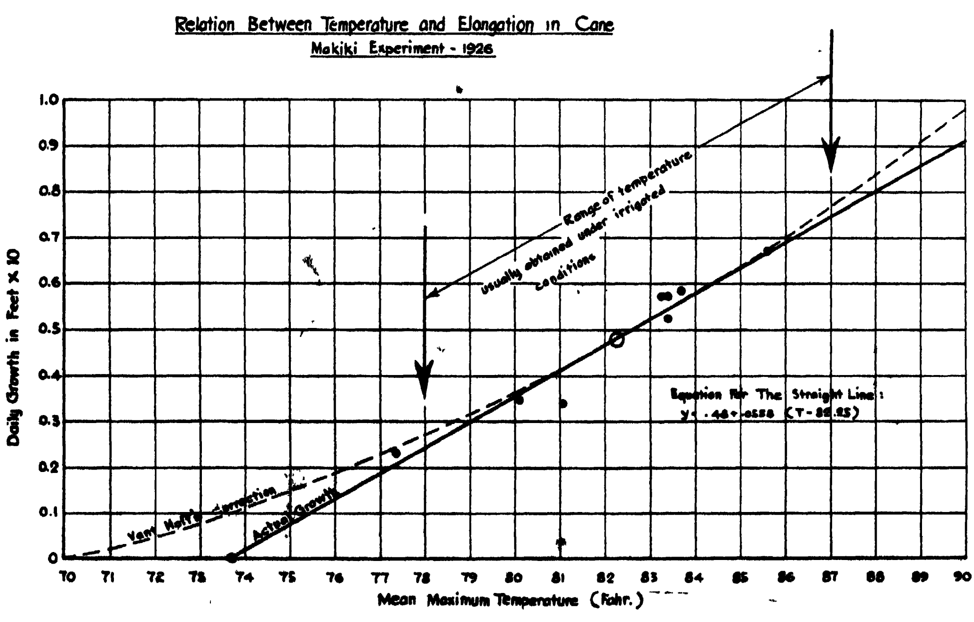

Fig. 9

Let us now estimate the elongation that we should obtain from assuming 70° of maximum temperature as the zero point of growth and that Van't Hoff's Law applies. We are now to find, if 82.25° produces an elongation of 0.48 foot, what should be the elongation at the other temperatures actually obtained in the experiment. Van't Hoff's Law states that the velocity of chemical reaction increases from one to two for every 18° F. rise of temperature. Assuming a uniform increase in the rate, between the limits of 70° and 88°, we calculate the velocities at different temperatures to be $\left(1 + \frac{t - 70}{18}\right)$. Multiplying this calculated velocity by the number of day-degrees, we obtain the relative units of elongation to be obtained under different temperature conditions. Table II and Fig. 9 give the values thus obtained.

TABLE II

Mean Maximum Temperature	Day-degrees	Reative Units of Growth When 71° = 1	Growth in Feet When 82.25° = 0.48 Foot
72°	2	2.25	0.05
74	4	4.90	.11
76	6	8.00	.19
78	8	11.54	.27
80	10	15.60	.36
82.25	12.25	20.59	.48
84	14	25.00	.58
88	16	36.00	.84

The relation between temperature and elongation is now seen to be non-linear, and in greater accord with known facts of plant physiology. However, Fig. 9 shows clearly that over the range of temperature obtained in this experiment (the same limited range of temperature exists between the winter and the summer months of our plantations) the straight line gives substantially the same values as the curve. For the sake of simplicity, we may then assume the straight line to be a good first approximation to the true relationship.

TECHNICAL APPENDIX B

Accumulated Day-Degrees and Yield

The final test of the soundness of the suggested measures would be—how far do the actual yields correlate with total warmth when other growth factors are more or less constant?

In the body of the report, it has been shown that in general there is a very good agreement between total warmth and per acre yield of some plantations. In the case of Pepeekeo, the correlation between total warmth and yield per acre for 22 crops (1911-1932) is found to be + .63. This is indeed a very high correla-

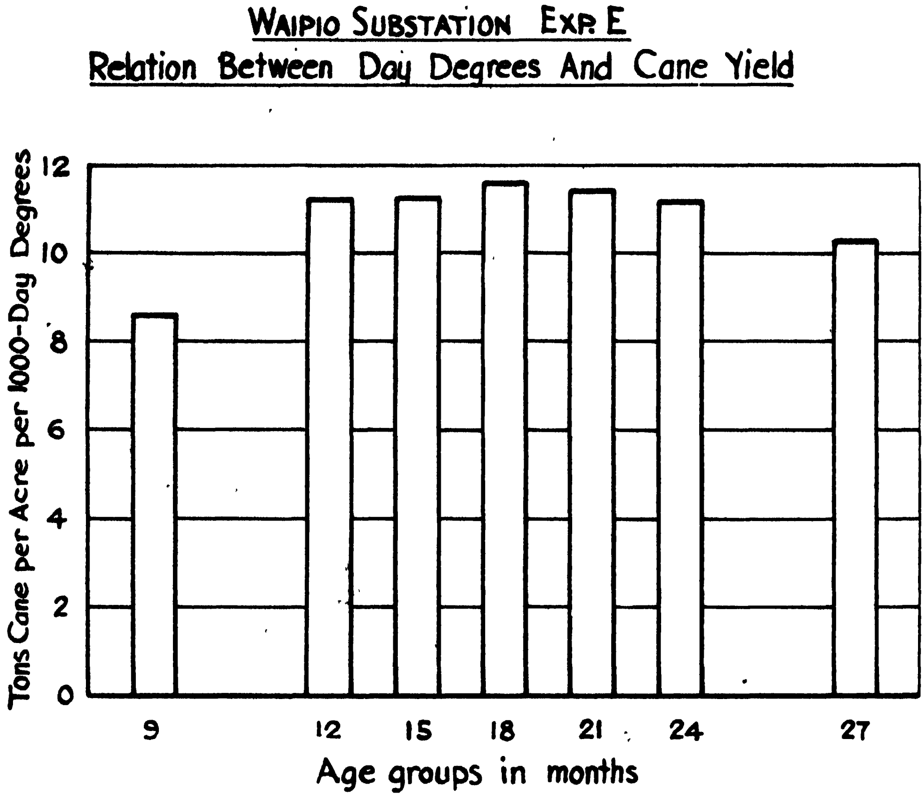

Fig. 10

tion, especially when we remember that no adjustment had been made in the yield data to allow for agricultural progress or cultural changes.

The data produced hereunder show that under more or less uniform cultural conditions there actually exists a greater correlation between total warmth and yield.

In Experiment E (1927-1929) at Waipio Substation of the H. S. P. A., the rate of cane yield with age was studied in relation to time of planting and harvesting. The harvesting results and other calculations are tabulated below:

VARIETY H 109—PLANT CANE ONLY

No. of Harvests	Age at Harvest (Calendar Months)	Tons Cane per Acre	Accumulated Day-degrees From the Date of Planting to Harvest	Tons Cane per 1000 Day-degrees
1	9	23.5	3484	6.7
2	10	39.5	3898	10.1
3	10	31.4	3692	8.5
4	7	26.4	2954	8.9
Average	9	30.2	3507	8.6
5	12	54.8	4987	11.0
6	12	45.9	4735	9.7
7	12	53.8	4706	11.4
8	12	53.1	4586	11.6
9	12	53.4	4284	12.5
Average	12	52.2	4660	11.2
10	15	70.7	6238	11.3
11	15	59.5	5543	10.7
12	15	65.1	5600	11.6
13	15	66.3	5916	11.2
14	15	59.3	5286	11.2
Average	15	64.2	5717	11.2
15	18	91.6	7046	13.0
16	18	72.2	6437	11.2
17	18	90.2	6930	13.0
18	18	68.6	6918	9.9
19	18	66.4	6123	10.9
Average	18	77.8	6691	11.6
20	19	107.6	7940	13.6
21	21	99.5	7767	12.8
22	22	80.0	7932	10.9
23	23	70.0	7755	9.0
Average	21	89.3	7849	11.4
24	24	125.6	9270	13.6
25	24	90.0	8769	10.3
26	24	82.0	8769	9.4
Average	24	99.2	8936	11.1
27	27	108.9	10272	10.6
28	27	96.4	9606	10.0
Average	27	102.6	9939	10.3

Fig. 10 shows the average tons of cane per 1000 day-degrees for the different age groups. We note that this average is practically the same for canes of 12 to 24 months of age, but that it falls off below 12 months and above 24 months. The low averages for very young and very old cane are explained by the fact that in the one, cane has had hardly enough time to form and that in the other, deterioration has set in. But the fact that the average figure for tons cane per acre per 1000 day-degrees is practically the same between 12 and 24 months of age, further confirms our assumption that the relation between growth and day-degrees is approximately linear within the limited range of temperature obtained on our plantations, and that accumulated day-degrees give a satisfactory measure of total effective warmth for crops that are neither too old nor too young.

A dot chart correlating yield and total day-degrees shows that the great deviations from the straight line of best fit were obtained only in the case of the old canes. From our knowledge of the details of this experiment we have reasons to believe that some of these latter harvests were not strictly comparable to the rest.

Without making any corrections for any known differences or without discarding any of the data we have correlated the yields with accumulated day-degrees.

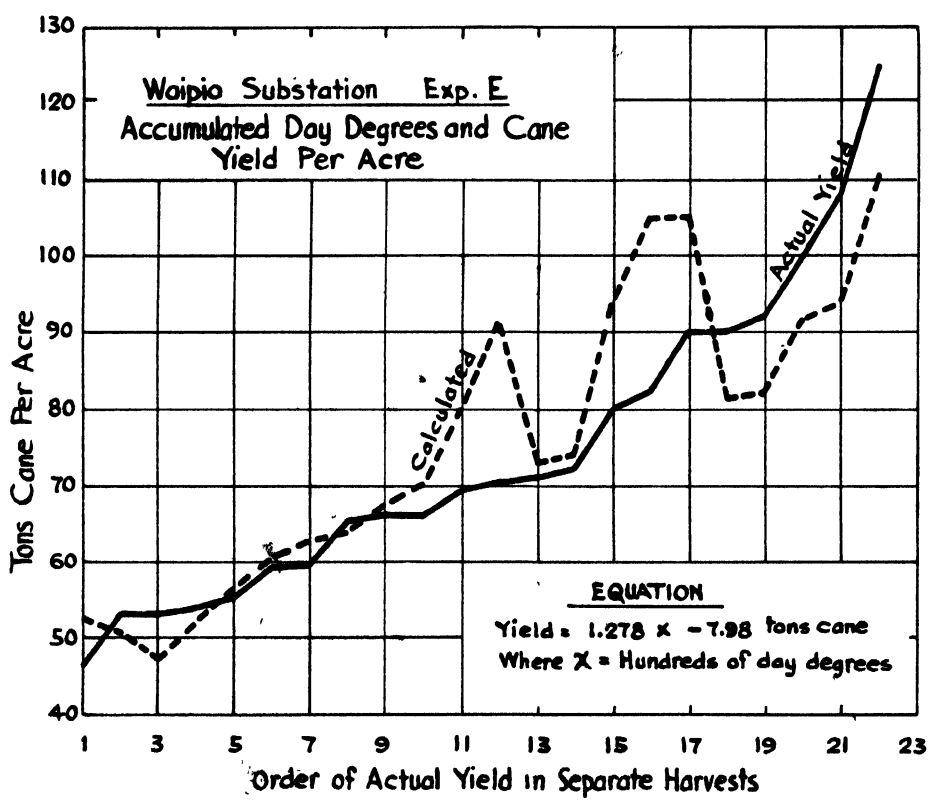

Fig. 11

The coefficient of correlation is + .899 for canes 12 to 18 months of age, + .852 when cane 21 months old is included and + .848 when all the harvests from 12 to 24 months are taken.

The magnitude of these coefficients leaves no doubt in one's mind that under uniform cultural conditions, accumulated day-degrees is the determining factor in cane yield.

Further study of the data shows that the correlation between yield and total day-degrees is closer than that between yield and age, that in this experiment tons cane per acre per 1000 day-degrees give us a better measure than tons cane per acre per month. This should not be wondered at for the expression "total day-degrees" includes the element of time.

The Effect of Various Intensities of Light on the Growth of the H 109 Variety of Sugar Cane

By J. P. Martin and R. C. Eckart

Introduction

Plant life is characterized by a continuous accumulation of organic compounds which are not absorbed from the environment in an elaborated condition, but are synthesized in the body of the plant itself from simpler substances taken by the plant from its surroundings. The first step in this process is called photosynthesis and is dependent upon light as a source of energy. This photosynthetic activity is also dependent upon the green pigment, chlorophyll, which is found in all green plants in specific cell inclusions called chloroplasts. The formation of this green pigment is also dependent upon light as well as temperature, oxygen, iron, and the amount of carbohydrates in the leaf. Thus, the importance of light consists in the fact that it is necessary for breaking the strong linkage between oxygen and carbon to produce certain carbohydrates, principally sugars. These carbohydrates are then transformed by further synthesis and enzyme activity without the aid of light into dozens of substances which go to make up the various parts of the plant.

Thus, the role of light in plant growth is one of major importance to the proper functioning of the photosynthetic process which supplies the plant with the food materials necessary for its normal growth. The assimilation of the products of photosynthesis within the leaf to form these plant food materials, and their eventual storage, is closely associated with photosynthesis. When this process of assimilation terminates with the formation and storage of sugars, the plants are called "saccharophilous" in distinction from "amylophilous," or plants which form and store starch.

Sugar cane being a light-loving and at the same time a saccharophilous plant, requires a large amount of light for the manufacture of sugar. When grown in the dark, the storage of sugars is greatly reduced and there is a marked accumulation of starch in the leaves, which is formed from not only the sugars: glucose, fructose, sucrose, galactose, mannose, and maltose, but also from other organic compounds. This fact is of primary importance, but closely associated with it are other growth peculiarities which tend also to reduce the amount of sugar manufactured and stored by the plant. It is with these latter abnormalities that this paper deals, and as no attempt was made to keep accurate temperature records or records of light intensity, photosynthetic rate, respiration, and the composition of the surrounding air, shade may be considered, for this purpose, the limiting factor of growth. It was realized that absolute scientific control of these factors would be impossible, so this experiment can merely be considered a "preliminary observational test" of the formative effects of various intensities of light on the growth of the H 109 variety of sugar cane.

Some idea of the degree of light intensity under the three conditions mentioned in this paper may be had by referring to Fig. 1.

Apparatus

The apparatus used consisted of two separate frames covered with one and two layers of unbleached muslin, respectively. The first will be referred to as Group II and the second as Group III, Group I being exposed to greenhouse conditions. Each group consisted of six 2-gallon pots arranged in a circle and supplied with a standard nutrient solution by the constant drip method from a 5-gallon bottle set in the center on a pedestal. Fig. 2 shows this method of feeding the plants and gives some idea of the construction of the test.

The variety of cane used was H 109, started from "top" three-eye cuttings. The young shoots were removed from the cuttings after suitable shoot roots had developed. The shoots were then planted in the pots in screened black sand and allowed to remain in the open for one week before subjecting them to the various light intensities.

Results

In less than a month the plants began to show definite changes, the most noticeable being the rapid growth of secondary shoots in Group I and the absence of shoots in the other two groups. The following illustration, Fig. 3, of Group I, taken on October 5, 1932, shows the numerous secondary shoots which have appeared and grown vigorously at the expense of the primary stalks. The leaves at this stage were normal as to width, texture, and color.

The next illustration, Fig. 4, of Group II, was taken on October 5, 1932, and shows the absence of secondary shoots and the stimulated growth of the primary stalks.

Fig. 5, of Group III, was also taken on October 5. The excessive shading of this group has stunted the growth of the plants in four ways: (1) spindly stalk, (2) narrow leaves, (3) no secondary shoot growth, and (4) exceptionally small root systems. Note the unusual length of the leaves.

The leaves of the plants in this group were a yellowish green in color and showed a tendency to dry up rapidly. The stalks were soft and although they grew rapidly for a short period, growth practically ceased after two months.

On October 5, two pots from Group I were transferred to Group III and two pots from Group III were transferred to Group I. The illustration shown in Fig. 6 was taken on October 5. Pots A and B are from Group III and Pots C and D are from Group I.

Within 10 days after this transfer, the plants moved from Group III to Group I, Pots A and B, began to send out secondary shoots, the new leaves became broader and greener and the primary stalks slowed up in growth. The plants moved from Group I to Group III, Pots C and D, became yellowish in color, many of the secondary shoots began to die, the new leaves came in narrow and the growth of the primary stalks was greatly increased.

The test was harvested on December 9, 1932, and representative plants from each group were photographed. Fig. 7 shows two plants from Group I. Their general appearance is one of vigor and normal condition. The plant on the left has 13 secondary shoots and the one on the right has 12.

In all cases the oldest secondary shoots outgrew the primary stalks at the expense of the latter. Fig. 9 shows two plants from Group II. The absence of secondary shoots and the excessive growth of the primary stalks are the outstanding features as compared with the plants shown in Fig. 7.

The stalks of these plants, Fig. 9, were heavy, the leaves normal as to color and width, but abnormally long and brittle. Fig. 8 shows two plants from Group III. Growth in this case became stunted after about two months, the leaves were pale in color, narrow, and elongated, with a tendency to dry out rapidly and shrivel up. The primary stalks were spindly and soft. The absence of secondary shoots is significant. The root systems were so small and shallow that they were barely able to support the plants in an upright position. These plants could not have survived this treatment for many more weeks.

Figs. 10 and 11 are of the plants which were moved from Group III to Group I (Pots A and B) and from Group I to Group III (Pots C and D), respectively.

Note the growth of secondary shoots in Pots A and B. These shoots appeared in less than 10 days after subjecting the plants to the light. The leaves became greener, wider, and normal in texture. The stalks became thicker and more rigid, and the new roots arising from the young secondary shoots, imbedded themselves throughout the entire "soil mass."

The secondary shoots in Pots C and D almost completely died out in less than six weeks after subjecting the plants to the shade of Group III. Growth of the primary stalks was stimulated, the leaves became elongated, brittle and pale in color. The plants as a whole, acquired all the light-deficiency symptoms of the other plants in this group. Table I gives the green and dry weights of all the plants and Charts I and II represent these weights graphically.

One of the most interesting disclosures at harvest was the condition of the root systems, those of Group I filling the whole pot, those of Group II occupying about one-half the space, and those of Group III being so meager that they were barely able to support the plants. This corresponds to the findings of one investigator in his studies of deciduous tree seedlings. He reports: "If the environment is unfavorable, especially as regards insufficient light, the root system is a miniature of the one that develops under favorable conditions." (1)

Another investigator working with various plants has reported the following: (2)

1. The per cent of dry matter increases with increasing light intensity.
2. The dry weight is directly proportional to light intensity.
3. With decreasing light intensity the plants tend to increase height.
4. Density of growth is increased with increasing light intensity.
5. There is a tendency to increase the chlorophyll concentration with decreasing light intensity until a critical intensity is reached. Further decrease in light intensity causes a decrease in the chlorophyll concentration.
6. Low light intensities tend to produce vegetative growth at the expense of flowers and fruit, top growth at the expense of root growth, large leaf area at the expense of leaf thickness (this does not seem to be true of the sugar cane plant) and succulence at the expense of sturdiness.

The abnormalities of sugar cane growth under shade, as referred to in this paper, are of course, closely associated with photosynthesis, in fact they are due to the abnormal or reduced functioning of the photosynthetic process in consideration of light intensity alone. So sensitive is the sugar cane plant to light that even the shade which occurs in the rows will cause abnormal growth and death to the young shoots, and many successive days of cloudy weather will greatly hinder the normal function of photosynthesis, thus causing a reduction in the sugar content of the plant.

SUMMARY

Sugar cane, being a saccharophilous and a light-loving plant, is sensitive to changes in light intensity. The major formative changes which the plants in this test underwent, under the various conditions of light intensity, may be summarized as follows:

Decreased light itensity:

1. Increases the height of the primary stalk.
2. Hinders secondary shoot development.
3. Causes the leaves to become narrow, elongated, and brittle.
4. Greatly reduces root development.
5. Increases the concentration of chlorophyll in the leaves up to a certain decreased intensity. A further decreased intensity decreases the chlorophyll concentration.
6. Reduces the per cent of dry matter.

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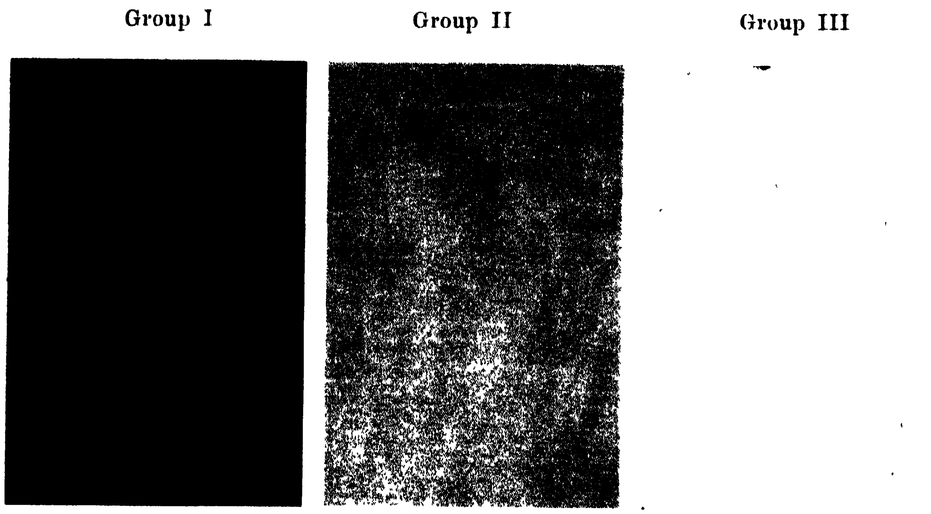


Fig. 1. Ten-minute exposures of 35 speed blue print paper under various conditions of light intensity. (10 a. m., August 11, 1932.)

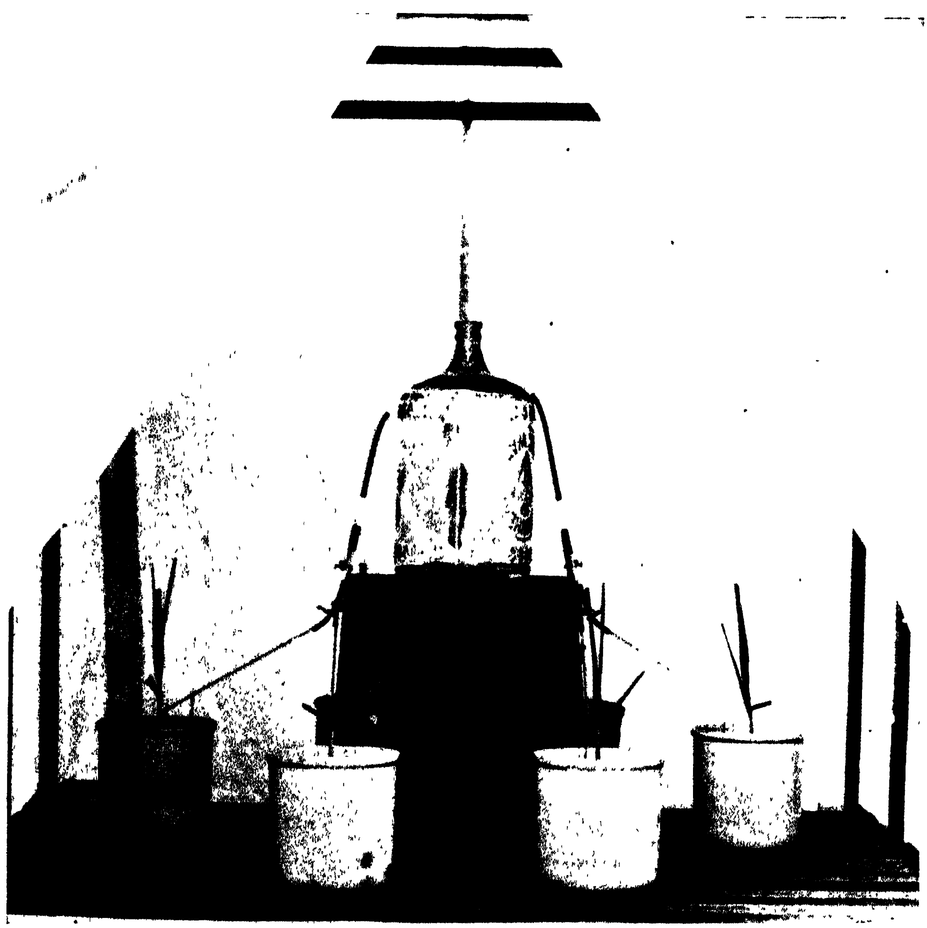


Fig. 2. Showing the method of growing H 109 cane plant (Group II) in reduced light. The method used in applying the nutrient solution is also shown.

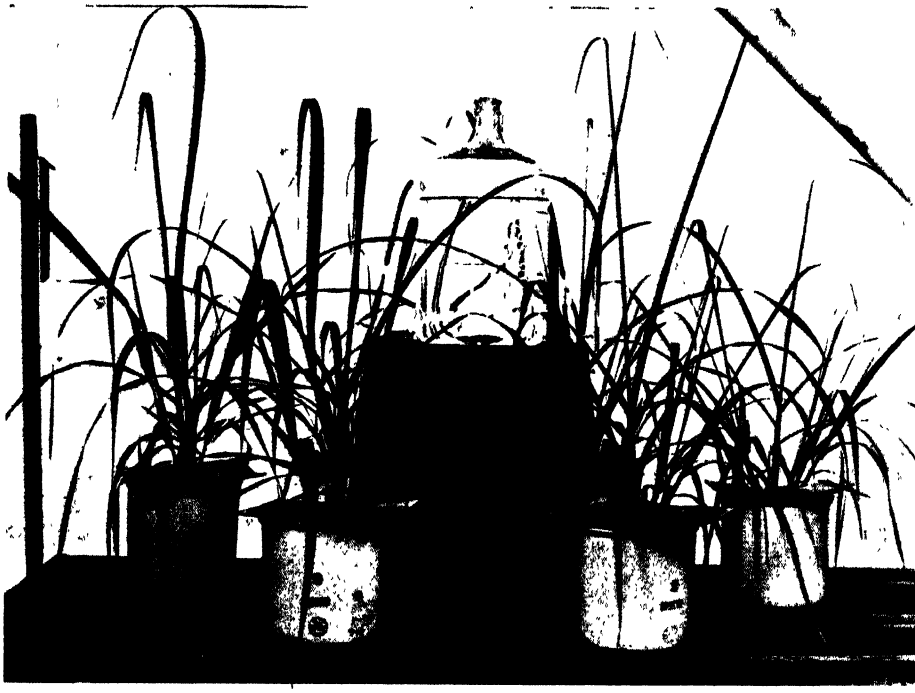


Fig. 3. Group I, showing H 109 cane plants, 56 days old, exposed to greenhouse conditions. Note secondary growth in each pot.

Fig. 4. Group II, showing H 109 cane plants, 56 days old, shaded by one layer of muslin. Note the absence of secondary shoots and stimulated growth of the primary stalks.

Fig. 5. Group III, H 109 cane plants, 56 days old, shaded by two layers of muslin. Note the absence of secondary shoots and the retarded growth of the plants as compared with those plants in Fig. 4.

Fig. 6. H 109 cane plants, aged 56 days. Pots A and B were moved from Group III to Group I, while Pots C and D were moved from Group I to Group III.

Fig. 7. H 109 cane plants from Group I, 120 days old. Grown under greenhouse conditions. Note development of secondary shoots.

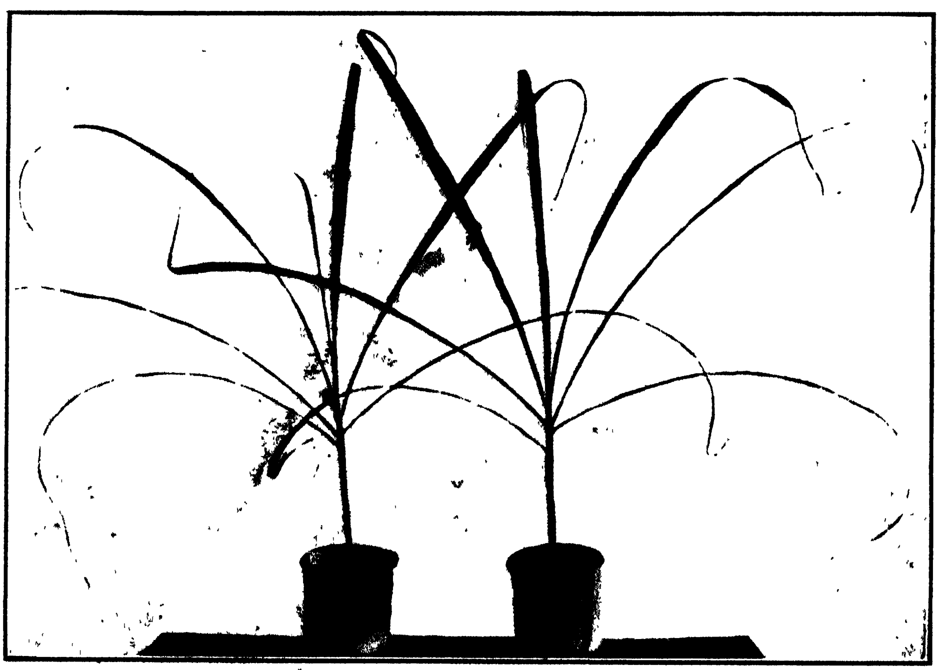


Fig. 8. H 109 cane plants from Group III, 120 days old, shaded by two layers of muslin. The primary stalks were considerably smaller than those in Group II. The leaves were unusually narrow and elongated. No secondary growth developed in these pots.

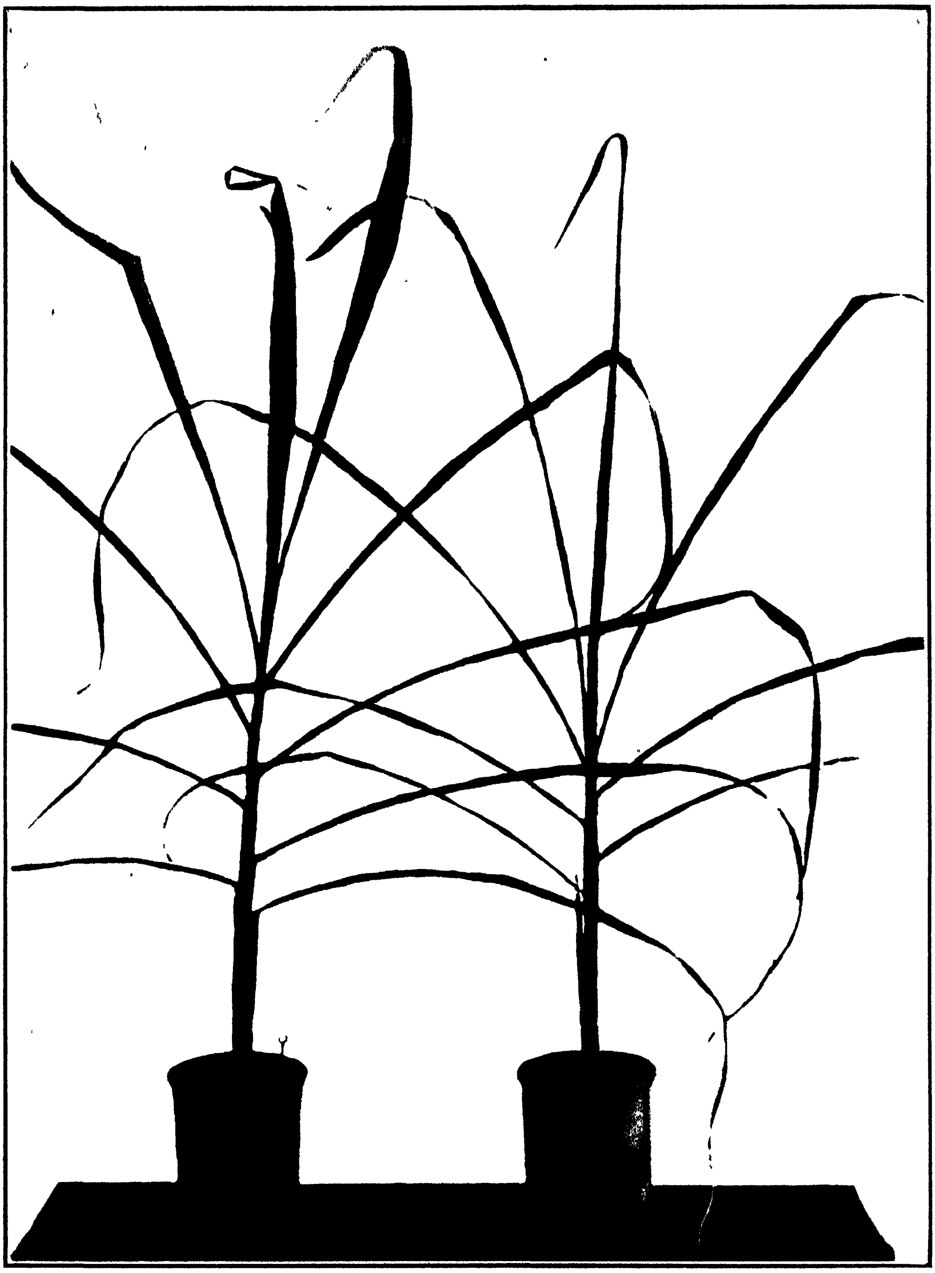


Fig. 9. H 109 cane plants from Group II, 120 days old, shaded by one layer of muslin. No secondary growth developed in these pots, but the primary stalks were larger than those in Groups I and III.

Fig. 10. These plants, at an age of 56 days, were transferred from Group III to Group I (see Fig. 6). Note development of secondary shoots after an exposure of 64 days to greenhouse conditions.

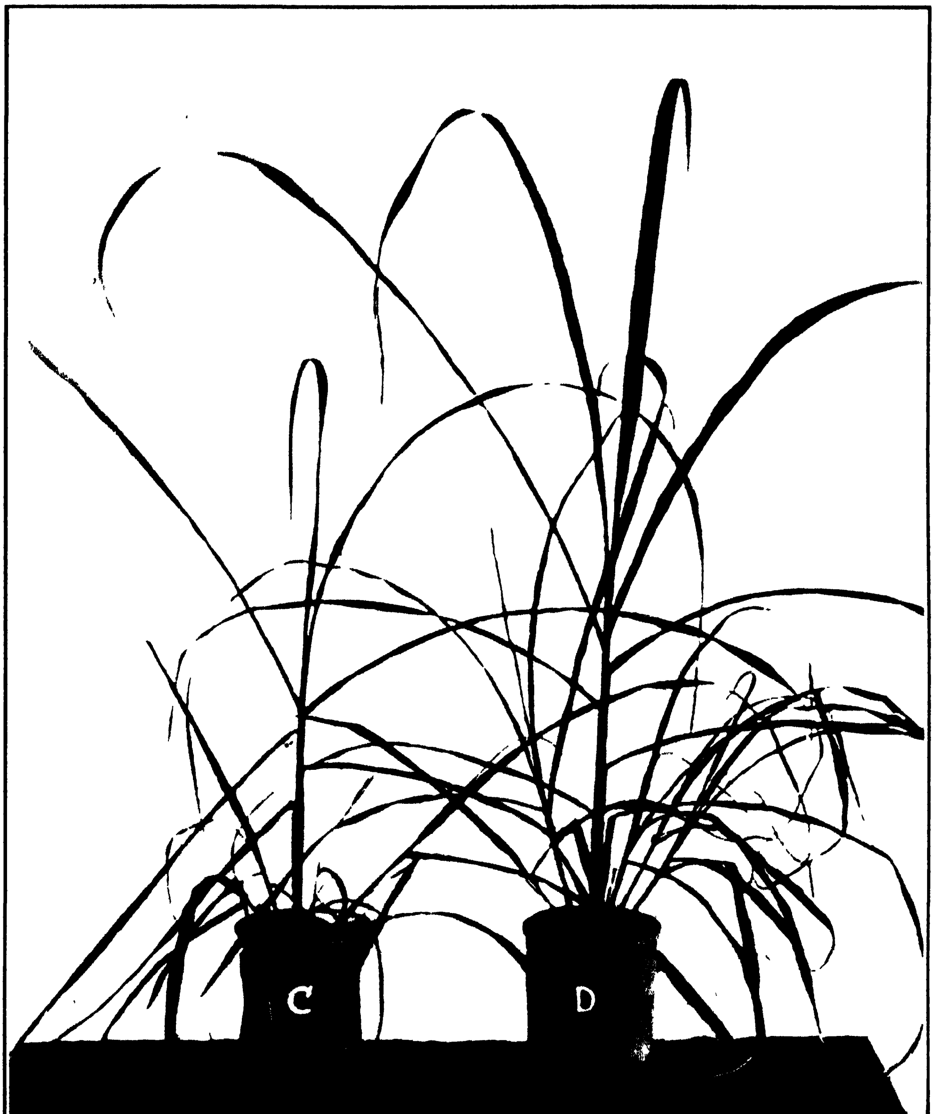


Fig. 11. These plants, at the age of 56 days, were transferred from Group I to Group III (see Fig. 6). Practically all the secondary shoots died, while the growth of the primary stalks was stimulated after an exposure of 64 days to reduced light conditions in Group III.

Total Green Weight in Grams of H109 Grown under Various Intensities of Light.

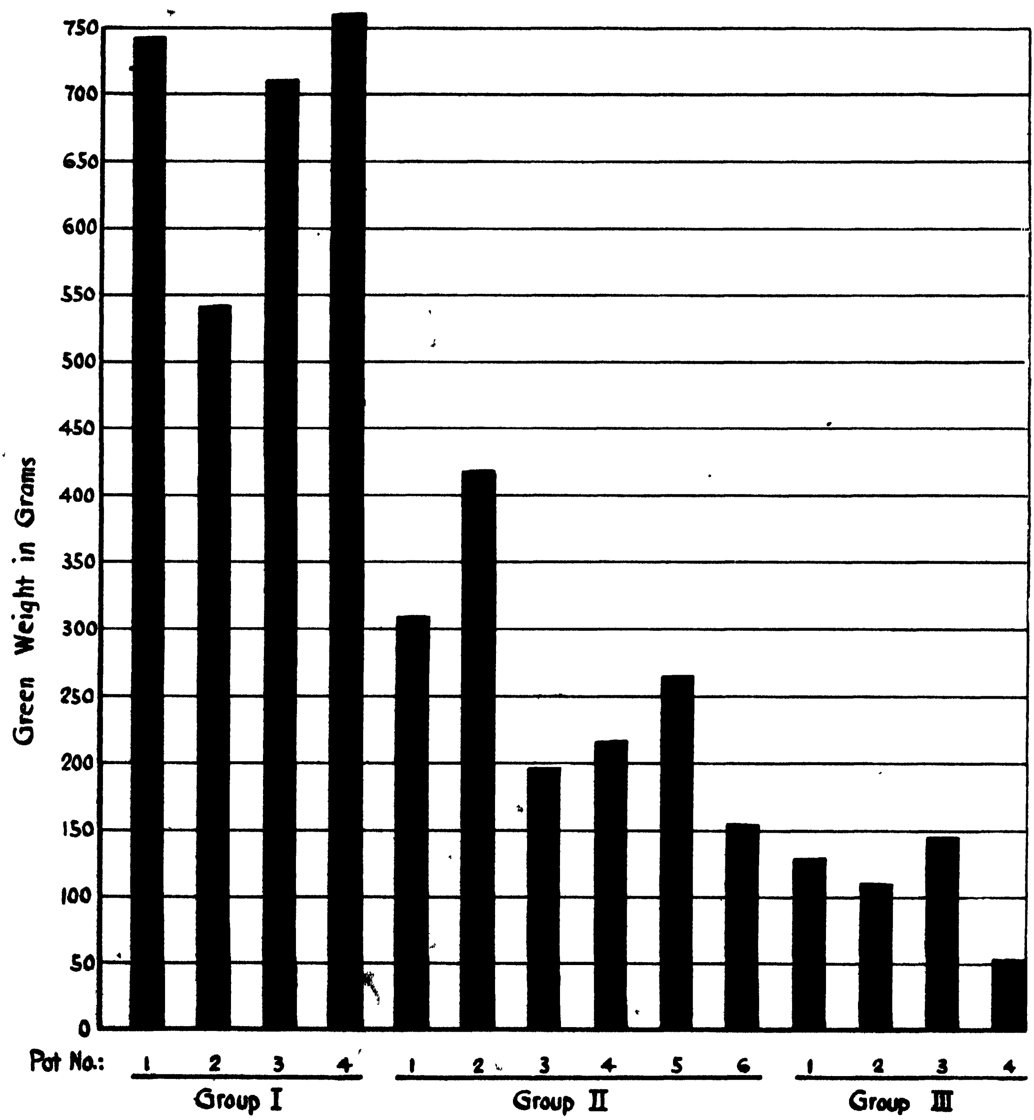


Chart I

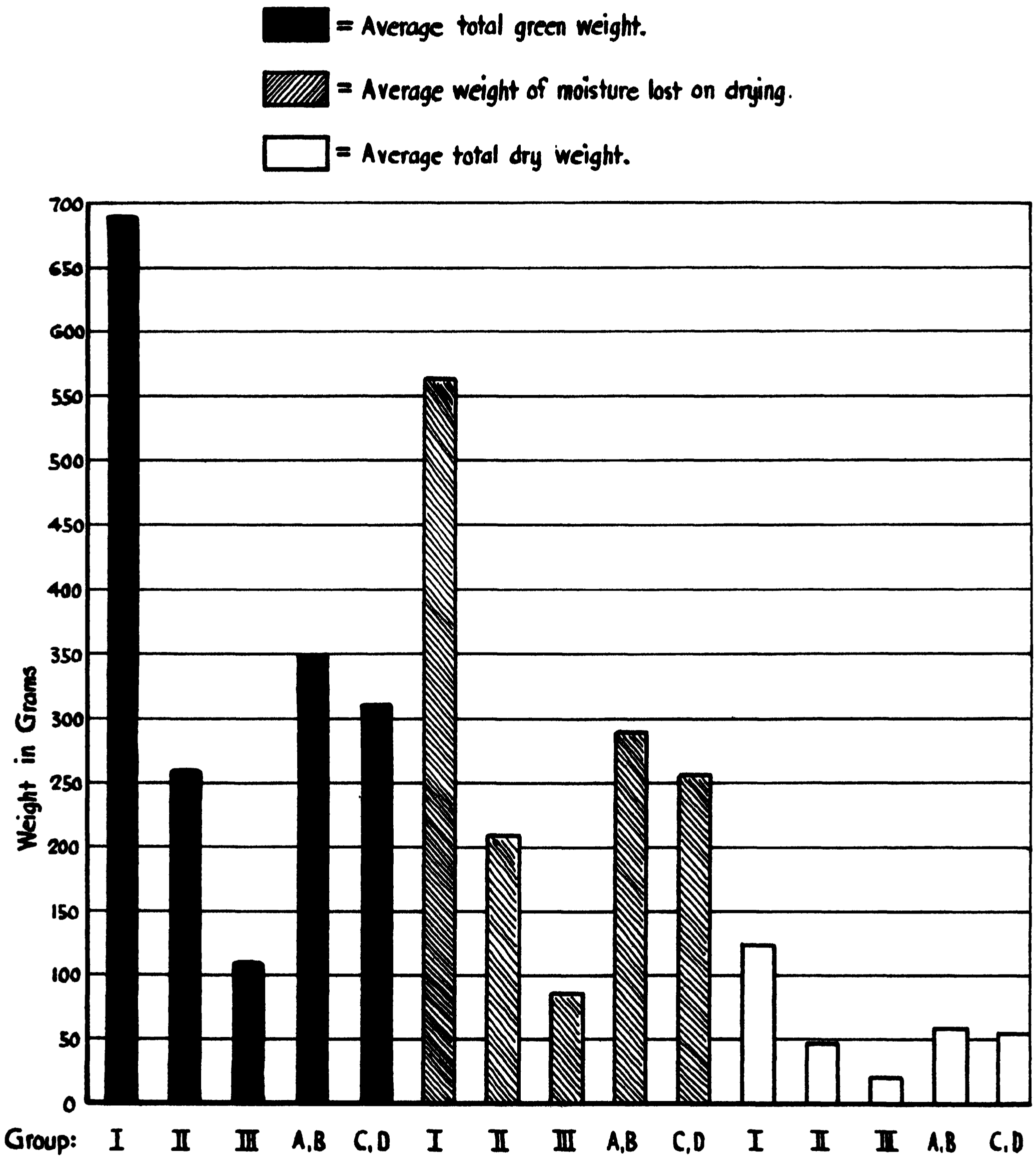

= Average total green weight.
= Average weight of moisture lost on drying.
= Average total dry weight.
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Weight in Grams
Group: I II III A,B C,D I II III A,B C,D I II III A,B C,D

Chart II

Green and Dry Weights in Grams of H109 Grown under Various Intensities of Light from Aug. 15 to Dec. 9, 1932.

Group	Pot No.	Green Weight	Dry Weight	Amount of Moisture Lost	No. of Shoots	Remarks
I Green - House Conditions	1	743.1	102.3	640.8	8	Excellent root development.
	2	542.5	90.0	452.5	12	
	3	710.3	140.0	570.3	13	
	4	763.0	168.1	594.9	10	
Average per Pot		689.72	125.1	564.62		
II Shaded With One Layer of Muslin	1	310.6	59.7	250.9	0	Root about half the size of those of Group I
	2	419.0	74.3	344.7	0	
	3	198.7	41.1	157.6	0	
	4	218.1	39.9	178.2	0	
	5	265.1	50.8	214.3	0	
	6	156.7	30.8	125.9	0	
Average per Pot		261.36	49.4	211.96		
III Shaded With Two Layers of Muslin	1	130.0	25.9	104.1	0	Roots barely able to hold the plants upright.
	2	111.5	24.5	87.0	0	
	3	146.5	27.0	119.5	0	
	4	52.3	10.0	42.3	0	
Average per Pot		110.07	21.85	88.2		
Moved From III to I on Oct. 5	A	275.0	44.2	230.8	6	Excellent root development.
	B	427.8	72.3	355.5	10	
Average per Pot		351.4	58.25	293.15		
Moved From I to III on Oct. 5	C	214.3	37.6	176.7	Died	Poor root systems.
	D	412.6	72.6	340.0	Died	
Average per Pot		313.45	55.1	258.35		

Annual Synopsis of Mill Data

By W. R. McAllep and W. L. McCleery

This is the ninth successive season in which production has exceeded previous records. During the year ending approximately September 30, the period covered by these data, factories in the Association produced 1,016,843 tons of sugar, an increase of 3 per cent over last year.

All factories in the Association have submitted data for this Synopsis. The number has been reduced from 39 to 38 as factory operations have been discontinued at Olowalu, following the consolidation of this plantation with Pioneer.

Factories are listed in the tabulations in the order of the average size of the crop for the past five years unless otherwise noted, and in other respects data are presented in a form closely comparable with previous Synopses. Some reductions in tabulated matter have been made where data are no longer as useful as in the past or where changes in data from year to year are small enough to warrant publication at less frequent intervals. The table of Apparent Boiling House Recovery has been discontinued as all but three factories now report sucrose data. The Summary of Losses also has been discontinued as losses calculated as a percentage of the pol in cane are readily available in the first of the large tables. Losses per cent cane and milling machinery have been omitted from the first of the large tables. Several items of mill data customarily included in a second and third large table have been omitted for this season, enabling us to combine these tables.

Varieties of Cane

Eight varieties have been ground to the extent of 1 per cent of the total crop, an increase of two. One of these, Badila, was included in Table 1 two years ago. Uba appears for the first time.

Yellow Caledonia and D 1135 together make up approximately a third of the crop, and H 109 somewhat more than one-half. P. O. J. 36 leads the less important varieties by a comfortable margin.

Increases over last season are recorded for H 109 and P. O. J. 36, and decreases for Yellow Caledonia, D 1135, Yellow Tip and Striped Tip. Considering the biennial nature of the crop, however, the trend is probably toward an increase rather than a decrease in D 1135. Also H 109 has probably passed the peak in percentage, notwithstanding the small increase over last season and a larger total tonnage than in any previous year.

The increase in P. O. J. 36 brings this variety from fifth to fourth place. It now shares with D 1135 the distinction of being the most widely distributed variety, both being reported from 25 factories.

The decline in the proportion of Yellow Caledonia continues steadily. Yellow Tip is decreasing rapidly, the proportion being less than half of the maximum

TABLE NO. 1
MAJOR VARIETIES OF CANE
(One per cent or more of total crop)

	H 109	Y. C.	D 1135	P. O. J. 36	Yellow Tip	Striped Tip	Badila	Uba	Others
H. C. & S. Co.	100	...	...	..	..	..	..	..	...
Oahu	98	...	1	..	..	..	..	..	1
Ewa	99	...	...	..	..	..	..	..	1
Waialua	96	...	1	..	..	..	..	..	3
Maui. Agr.	96	...	...	..	..	..	..	..	4
Pioneer	96	...	1	1	..	..	..	..	2
Lihue	48	...	3	17	14	..	10	..	8
Olaa	...	75	19	6	..	..	..	..	...
Haw. Sug.	99	...	1	..	..	..	..	..	...
Kekaha	97	...	...	..	..	..	..	..	3
Honolulu	98	...	...	2	..	..	..	..	...
Haw. Agr.	...	39	50	1	..	..	..	..	10
Onomea	...	81	5	8	4	..	..	..	2
Hilo	...	87	9	2	..	..	..	..	2
Honokaa	2	1	68	8	..	..	..	17	4
Makee	53	11	...	9	8	..	7	..	12
McBryde	84	...	6	5	1	..	..	..	4
Wailuku	95	...	...	..	..	..	..	..	5
Hakalau	...	65	18	8	7	..	..	..	2
Kahuku	96	...	...	1	..	..	..	..	3
Laupahoehoe	...	22	68	2	7	..	..	..	1
Koloa	67	2	...	15	4	..	..	..	12
Waiakea	...	96	2	..	..	..	..	..	2
Hamakua	...	...	84	..	9	..	..	..	7
Pepeekeo	...	90	4	3	2	..	..	..	1
Hutchinson	...	24	54	16	..	..	..	..	6
Paauhau	...	...	57	18	14	..	..	..	11
Kohala (Hawi)	...	...	13	10	..	47	..	..	30*
Kohala	...	...	29	4	..	15	..	..	52†
Honomu	...	83	10	4	..	..	..	..	3
Kaiwiki	...	9	88	..	1	..	..	..	2
Waimanalo	61	...	...	23	..	..	..	..	16‡
Kilauea	3	4	...	4	14	1	28	35	11
Waianae	100	...	...	..	..	..	..	..	...
Kaeleku	...	94	1	2	..	..	..	..	3
Union Mill	...	...	12	13	..	65	..	..	10
Niulii	...	...	45	9	..	36	..	..	10
Waimea	99	...	...	..	..	..	..	..	1
True Average 1932	54.5	17.6	13.4	4.1	2.1	1.5	1.0	1.0	4.8
" " 1931	54.2	18.8	13.7	2.6	3.0	2.1	0.7	0.9	4.0
" " 1930	56.6	19.9	12.3	0.7	3.5	1.6	1.2	0.7	3.5
" " 1929	53.1	21.5	13.0	0.3	4.3	2.1	0.5	0.7	4.5
" " 1928	54.7	20.7	12.9	..	4.9	2.2	0.3	0.5	3.8
" " 1927	53.1	23.7	11.8	..	4.0	1.6	0.4	0.1	5.3
" " 1926	48.7	25.6	12.1	..	4.5	2.1	0.5	..	6.5
" " 1925	42.7	30.7	11.9	..	2.7	2.1	0.4	..	9.5
" " 1924	38.1	32.6	12.0	..	2.3	2.0	0.1	..	12.9
" " 1923	30.7	36.3	11.2	..	1.2	1.6	0.2	..	18.8

* K107, 23%
† K107, 44%
‡ P. O. J. 2878, 6%

reached in 1928. Though Striped Tip makes up but a small proportion of the crop, and often fluctuations from one season to the next have been relatively large, this variety has maintained its relative position more consistently than any other during the whole of the 15-year period for which figures are available. Maximum and minimum percentages have been 2.6 and 1.5 respectively.

Minor Varieties: This classification includes varieties making up 1 per cent of the crop of any factory. The following 16 have been reported:

MINOR VARIETIES

One Per Cent or More of the Crop of Any Factory

1. K 107	5. H 456	9. St. Mex.	13. McB. 6
2. UD 1	6. P O J 2878	10. Manoa 213	14. UD 79
3. K 202	7. P O J 213	11. K K 456	15. N Uba
4. H 8965	8. UD 50	12. H 8906	16. Nalo 13

The above are listed in the order of the tonnage as reported, but this order may not be particularly accurate as small quantities of minor varieties are often omitted from Synopsis reports. The amount of K 107 reported was but slightly less than 1 per cent of the total crop.

Rose Bamboo and D 117 have disappeared from the minor variety classification this year, having joined Lahaina in the group of former major varieties which no longer appears even in the minor variety classification.

Six of the above varieties appear in the Synopsis for the first time. Among these may be mentioned P. O. J. 2878, which was reported from 12 factories and on its first appearance makes up .22 per cent of the total crop.

Quality of Cane

The quality of cane is poorer than last season to the extent of .12 of a ton of cane per ton of sugar. In 1927 only was the quality poorer, the average quality ratio then being 8.91 against the present average of 8.84.

Averages for fiber per cent cane do not indicate changes of any particular significance in the last few seasons.

In one respect the cane has been better; that is, purities have improved. This holds true for all Islands, though the improvement in purity on Hawaii has been very small. The decrease in cane quality is on account of lower pol, this having much more than offset the improvement in purity. Oahu is the only island where the pol has increased. With this increase, and better purity, the quality has improved .15. Decreases in quality on Kauai and Maui have been of about the same order as the improvement on Oahu. The decrease on Hawaii is equivalent to .4 in quality ratio, bringing the quality ratio to above 10, the poorest yearly average on record for any island. The decrease in quality on the island of Hawaii is principally responsible for the decrease in the average quality this season.

Decreases on the island of Hawaii are also responsible for a large part of the perturbing decrease in the average quality of cane during the past 15 years. Data on trend in cane quality during this period, as calculated by the usual method of least squares, follow. Trends for both quality ratio and the corresponding yield per cent cane are given, but the latter should be used for comparative purposes.

TABLE NO. 2

COMPOSITION OF CANE BY ISLANDS

	Hawaii	Maui	Oahu	Kauai	Whole Group
1923					
Pol	12.09	13.61	12.99	12.94	12.78
Per cent Fiber	13.14	12.01	12.86	12.99	12.82
Purity 1st Expressed Juice	87.61	88.65	85.52	86.58	87.05
Quality Ratio	9.04	7.86	8.43	8.36	8.50
1924					
Pol	12.44	14.34	13.48	13.34	13.26
Per cent Fiber	12.99	12.16	12.72	12.94	12.74
Purity 1st Expressed Juice	87.98	89.19	87.02	87.31	87.86
Quality Ratio	8.78	7.53	8.10	8.06	8.19
1925					
Pol	12.35	14.42	13.52	13.24	13.22
Per cent Fiber	12.92	12.40	12.60	12.91	12.74
Purity 1st Expressed Juice	88.02	89.36	87.11	87.19	87.92
Quality Ratio	8.84	7.42	8.12	8.15	8.22
1926					
Pol	12.53	14.66	13.40	13.03	13.24
Per cent Fiber	12.90	12.24	12.72	12.46	12.65
Purity 1st Expressed Juice	87.59	89.03	86.61	86.68	87.45
Quality Ratio	8.73	7.36	8.23	8.33	8.24
1927					
Pol	11.34	14.00	12.61	12.07	12.32
Per cent Fiber	12.84	11.98	12.29	12.65	12.49
Purity 1st Expressed Juice	86.27	87.85	85.87	85.17	86.28
Quality Ratio	9.73	7.71	8.78	9.11	8.91
1928					
Pol	11.57	14.13	13.09	12.09	12.55
Per cent Fiber	12.58	12.56	12.13	12.82	12.50
Purity 1st Expressed Juice	86.60	88.76	86.84	85.16	86.84
Quality Ratio	9.54	7.55	8.39	9.11	8.72
1929					
Pol	11.80	14.56	13.49	12.64	12.90
Per cent Fiber	12.53	13.24	12.28	12.61	12.62
Purity 1st Expressed Juice	86.65	89.14	87.17	85.97	87.18
Quality Ratio	9.45	7.35	8.14	8.69	8.50
1930					
Pol	11.30	13.77	13.05	12.67	12.49
Per cent Fiber	12.73	12.92	12.35	12.57	12.63
Purity 1st Expressed Juice	86.59	88.60	86.98	86.34	87.04
Quality Ratio	9.84	7.79	8.42	8.55	8.76
1931					
Pol	11.51	14.30	13.17	12.55	12.63
Per cent Fiber	12.52	13.04	11.98	12.75	12.53
Purity 1st Expressed Juice	86.18	88.26	86.31	85.49	86.47
Quality Ratio	9.66	7.52	8.42	8.73	8.72
1932					
Pol	11.16	14.02	13.23	12.35	12.42
Per cent Fiber	12.44	13.06	12.29	12.63	12.56
Purity 1st Expressed Juice	86.25	88.71	87.15	85.69	86.86
Quality Ratio	10.05	7.63	8.27	8.89	8.84

TREND IN CANE QUALITY 1918—1932

	Quality Ratio	Yield Per Cent Cane
Maui	+ .19	— .35
Oahu	+ .44	— .62
Kauai	+ .60	— .80
Hawaii	+1.18	—1.30
Average	+ .69	— .94

When we consider that between 35 and 40 per cent of the total cane tonnage is on Hawaii, it is apparent that decreases in quality on that island have been responsible for fully one-half of the decrease in the average quality of cane.

While studying data on cane quality during this period, it was noted that there has been a fairly well defined tendency for fluctuations in quality to follow recurring cycles of approximately five years each.

Chemical Control

The introduction of the Oliver-Campbell filter into the industry with the attendant use of screened bagasse as a filter aid brings up the question of accounting for the sugar in this bagasse. This sugar has already been accounted for in the loss in bagasse and if it again appears as a part of the loss in filter cake, we have a duplication of losses with a corresponding error in undetermined loss.

Determining the amount of sugar thus introduced is somewhat troublesome. The screened bagasse is not weighed, rendering it necessary to estimate the weight indirectly from fiber determinations. Also it is higher in moisture and lower in pol than the average bagasse, rendering separate analyses necessary. Careful determinations throughout the season at Koloa indicate that it amounts to about .04 per cent of the pol in cane under conditions at that factory. While the amount of sugar involved is not large, it is a fairly large part of the amount to which the filter cake loss can be reduced with this equipment and an appreciable part of the usual figures for undetermined loss. The loss in filter cake should be corrected for the sugar thus introduced by deducting this sugar from the total in filter cake. Preferably, the determination of this correction should be a part of the regular chemical control, but in view of the small amount of sugar involved, corrections estimated from determinations made periodically may be found sufficiently accurate.

Koloa's data have been corrected for the sugar thus introduced. We have not been informed that a similar correction has been made at other factories using Oliver-Campbell equipment.

Comparisons of actual and theoretical boiling house recoveries based on sucrose are in Table 3. The usual table based on pol has been omitted, figures for the three factories from which sucrose data have not been received being included in Table 3 with the notation that they are calculated from pol data.

There is little change in the tendency to report high figures for recovery on available. Twenty-one of the 38 factories report over 100 per cent. Four of the factories on a sucrose basis report over 101 per cent.

TABLE NO. 3

TRUE BOILING-HOUSE RECOVERY

Comparing per cent sucrose available and recovered

Factory	Available	Obtained	% Recovery on Available	Molasses Produced on Theoretical	
				s. j. m. Formula	Gravity Solids*
H. C. & S. Co.	93.05	93.82	100.8	86.0	90.3
Oahu	93.10	93.71	100.7	90.0	95.2
Ewa	92.54	92.62	100.1	95.3	96.3
Waialua	92.49	92.88	100.4	83.2	85.9
Maui. Agr.	93.09	93.85	100.8	86.1	88.0
Pioneer	92.81	91.35	98.4	102.2	97.0
Lihue	91.38	91.39	100.0	90.0	91.1
Olaa	91.63	91.14	99.5	96.7	95.4
Haw. Sug.	93.25	93.75	100.5	94.2	98.1
Kekaha	92.43	90.31	97.7	93.8	86.5
Honolulu	93.02	89.83	96.6	99.6	85.3
Haw. Agr.	92.32	90.37	97.9	104.3	96.0
Onomea	91.28	92.03	100.8	88.8	92.1
Hilo	90.57	90.05	99.4	86.5	85.3
Honokaa†	88.06	88.80	100.8	....	89.5
Makee	89.61	88.59	98.9	85.2	82.6
McBryde	90.95	90.22	99.2	92.6	91.3
Wailuku	92.58	92.57	100.0	91.0	92.6
Hakalau	91.81	92.23	100.5	91.5	93.4
Kahuku	91.48	92.76	101.4	88.0	....
Laupahoehoe	93.16	92.88	99.7	88.2	87.2
Koloa	91.94	92.19	100.3	92.2	93.9
Waiakea	90.41	91.25	100.9	83.5	87.6
Hamakua	91.44	93.51	102.3	81.8	90.9
Pepeekeo	91.06	91.48	100.5	93.1	93.6
Hutchinson	91.94	92.89	101.0	83.4	87.6
Paauhau	89.75	88.32	98.4	99.1	94.1
Kohala (Hawi)	88.83	89.54	100.8	83.4	86.9
Kohala	89.42	88.42	98.9	101.0	97.9
Honomu	91.15	92.56	101.5	85.0	90.8
Kaiwiki	89.85	88.80	98.8	100.8	96.1
Waimanalo	88.17	88.48	100.4	88.9	90.1
Kilauea	86.40	86.03	99.6	87.6	88.9
Waianae	92.96	91.32	98.2	91.3	85.1
Kaeleku†	87.32	91.81	105.1	....	91.2
Union Mill	90.36	89.59	99.1	88.9	86.3
Niulii	88.15	86.71	98.4	77.7	75.1
Waimea†	90.13	86.77	96.3	....	76.5

* The theoretical amount of gravity solids in final molasses assumed to be gravity solids in syrup, less solids accounted for in commercial sugar.

† As sucrose in syrup and sugar have not been reported, gravity purities have been estimated by adding 0.8 and 0.3 to the apparent purities of syrup and sugar.

TABLE NO. 4
GRAVITY SOLIDS AND SUCROSE BALANCES

Factory	GRAVITY SOLIDS PER 100 GRAVITY SOLIDS IN MIXED JUICE				SUCROSE PER 100 SUCROSE IN MIXED JUICE			
	Filter Cake	Commercial Sugar	Final Molasses	Undetermined	Filter Cake	Commercial Sugar	Final Molasses	Undetermined
H. C. & S. Co.	4.7	80.2	13.6	1.5	0.54	93.31	5.98	0.17
Oahu	5.3	78.5	15.1	1.1	0.19	93.53	6.21	0.07
Ewa	6.8	75.5	17.0	0.7	0.25	92.39	7.11	0.25
Waialua	4.4	78.3	14.7	2.6	0.22	92.68	6.25	0.85
Maui Agr.	..	83.8	14.3	1.9	...	93.85	5.95	0.20
Pioneer	5.1	76.5	17.6	0.8	0.25	91.12	7.35	1.28
Lihue	4.7	75.0	18.4	1.9	0.45	90.98	7.76	0.81
Olaa	4.0	76.6	18.4	1.0	0.14	91.01	8.09	0.76
Haw. Sug.	3.5	80.2	15.8	0.5	0.12	93.64	6.37	—0.13
Kekaha	3.8	77.4	16.0	2.8	0.22	90.11	7.10	2.57
Honolulu	5.4	75.6	16.3	2.7	0.40	89.47	6.95	3.18
Haw. Agr.	2.8	77.7	18.7	0.8	0.26	90.14	8.01	1.59
Onomea	4.5	76.7	17.3	1.5	0.08	91.96	7.74	0.22
Hilo	5.4	73.5	17.9	3.2	0.27	89.81	8.16	1.76
Makee	5.4	71.2	19.3	4.1	0.46	88.18	8.85	2.51
McBryde	4.5	73.3	20.1	2.1	0.44	89.82	8.38	1.36
Wailuku	4.9	78.6	15.1	1.4	0.49	92.12	6.75	0.64
Hakalau	4.8	76.7	17.3	1.2	0.15	92.09	7.49	0.27
Kahuku	..	...	...	..	0.26	92.52	7.50	—0.28
Laupahoehoe	3.1	79.5	15.1	2.3	0.13	92.76	6.03	1.08
Koloa	5.2	75.1	18.4	1.3	0.17	92.03	7.43	0.37
Waiakea	5.0	74.7	17.6	2.7	0.53	90.77	8.01	0.69
Hamakua	..	80.4	17.8	1.8	...	93.51	7.00	—0.51
Pepeekeo	6.4	73.4	19.2	1.0	0.29	91.21	8.32	0.18
Hutchinson	5.0	76.7	15.9	2.4	0.12	92.78	6.72	0.38
Paauhau	5.7	73.1	20.0	1.2	0.73	87.68	10.16	1.43
Kohala (Hawi)	6.5	70.8	19.6	3.1	0.92	88.72	9.32	1.04
Kohala	5.1	71.8	22.7	0.4	0.68	87.82	10.69	0.81
Honomu	6.6	74.8	16.8	1.8	0.31	92.27	7.52	—0.10
Kaiwiki	4.1	74.7	20.6	0.6	0.66	88.21	10.23	0.90
Waimanalo	6.2	68.9	22.5	2.4	0.54	88.00	10.52	0.94
Kilauea	5.0	66.9	24.7	3.4	1.38	84.84	11.92	1.86
Waianae	4.1	78.0	15.1	2.8	0.37	90.98	6.43	2.22
Union Mill	7.1	72.4	17.7	2.8	0.27	89.35	8.57	1.81
Niulii	4.1	71.3	18.4	6.2	0.99	85.85	9.21	3.95

Factory	Cane Sucrose	MIXED JUICE		SYRUP		SUGAR		Undetermined Loss per 100 Sucrose in cane
		Sucrose	Gravity Purity	Gravity Purity	Increase in Purity	Sucrose	Sucrose per 100 Sucrose in cane	
H. C. & S. Co.	14.59	12.31	88.54†	88.54	0	98.23	91.43	0.16
Oahu	13.73	11.72	86.64	87.36	0.72	98.36	92.07	0.07
Ewa	13.60	11.58	84.16	86.5	1.34	98.48	90.69	0.24
Waialua	13.57	11.65	85.7	87.3	1.6	98.50	90.99	0.83
Maui Agr.	14.61	12.35	88.03†	88.31	0.28	98.16	91.77	0.19
Pioneer	13.76	12.09	85.32	86.85	1.53	97.99	89.15	1.25
Lihue	11.71	10.76	83.6	84.9	1.3	98.20	88.56	0.79
Olaa	11.40	10.48	85.3	86.7	1.4	98.46	88.37	0.74
Haw. Sug.	14.49	12.03	86.05	87.71	1.66	98.56	91.83	—0.13
Kekaha	13.70	12.29	87.03	88.0	0.97	98.31	87.65	2.50
Honolulu	14.27	12.06	86.95	89.0	2.05	100.0	87.33	3.11
Haw. Agr.	11.97	10.77	86.57	87.26	0.69	98.23	87.75	1.54
Onomea	11.11	9.41	84.18	86.06	1.88	98.14	90.37	0.21
Hilo	10.93	9.80	83.69	84.9	1.21	97.76	87.96	1.73
Makee	11.58	10.16	82.3	83.77	1.47	97.96	84.72	2.41
McBryde	11.86	9.82	82.18	83.76	1.58	97.92	87.77	1.32
Wailuku	13.52	11.03	86.9	88.4	1.5	98.50	90.76	0.63
Hakalau	10.72	9.07	84.38	85.8	1.42	97.44	90.68	0.27
Kahuku	11.30	10.18	81.99	84.75	2.76	98.7	90.45	—0.27
Laupahoehoe	11.92	10.44	86.93	87.48	0.55	98.63	90.40	1.05
Koloa	11.67	9.77	83.08	84.97	1.89	98.44	89.63	0.36
Waiakea	11.58	10.01	83.54	85.17	1.63	98.34	88.09	0.67
Hamakua	11.37	10.86	84.98†	84.64	—0.34	98.36	90.74	—0.50
Pepeekeo	11.14	10.16	82.37	84.75	2.38	98.51	89.05	0.18
Hutchinson	11.90	10.22	84.08	85.29	1.21	97.55	90.56	0.37
Paauhau*	11.04	9.80	83.98	85.7	1.72	96.96	85.38	1.39
Kohala (Hawi)	11.20	10.53	81.19	83.55	2.36	98.22	86.61	1.02
Kohala	11.41	10.04	82.77	84.56	1.79	98.45	85.15	0.78
Honomu	11.08	9.10	83.59	85.42	1.83	98.22	90.26	—0.10
Kaiwiki	12.12	11.77	85.49	86.51	1.02	98.02	85.03	0.86
Waimanalo	11.54	9.68	79.28	81.38	2.10	97.33	86.70	0.93
Kilauea	10.43	9.81	79.76	80.41	0.65	97.57	81.16	1.78
Waianae	14.28	12.56	86.21	87.67	1.46	97.85	88.74	2.16
Union Mill	11.13	10.91	83.41	85.69	2.28	97.86	83.46	1.69
Niulii	10.10	9.73	84.02	84.85	0.83	98.35	80.17	3.69
‡True Average 1932	12.60	11.00	85.15	86.46	1.31	98.22	89.48	0.74
" " 1931	12.75	11.17	84.74	85.78	1.04	98.05	88.61	0.89
" " 1930	12.67	11.08	85.35	86.49	1.14	98.05	88.90	0.89
" " 1929	13.08	11.44	85.58	86.60	1.02	98.00	88.75	1.05
" " 1928	12.69	11.22	85.15	86.23	1.08	97.86	88.49	1.21
" " 1927	12.46	11.01	84.53	85.86	1.33	97.79	87.96	1.13
" " 1926	13.35	11.68	85.38	86.66	1.28	97.67	88.41	1.20

*Sucrose in bagasse and filter cake is assumed to be the same as pol.
†Clarified juice. ‡Refinery data from Honolulu not included in averages.

Both sets of calculations of molasses produced on the theoretical are in Table 3. Averages indicate a slight tendency toward an increase in molasses production per cent theoretical in the past few years. This year the average, calculated with the s. j. m. formula, is 91.3. On the gravity solids basis the average is 91.1. Last year the averages were 90.6 and 89.0 respectively. Data for individual factories vary to about the usual extent.

The new divisor for calculating sucrose, adopted when the Methods of the Association of Hawaiian Sugar Technologists were revised in 1931, was substituted for the Herzfeld divisor at the beginning of the season. Soon afterward it became apparent that sucrose determinations were too low. About June 1, a change back to the Herzfeld divisor was made and data were recalculated to the old basis so that sucrose figures for this season would be on the same basis as in previous years. Average differences between pol and sucrose in mixed juice and syrup are practically the same as last season, but the changes in the divisor have caused an irregularity in sucrose in sugar, the average appearing to be approximately .1 too high in comparison with data for previous years.

Unsatisfactory results with the new sucrose divisor were caused by two inaccuracies rather than by the divisor itself. The temperature correction factor in the sucrose formula, which had been continued unchanged, is not correct, and pipettes customarily used for measuring out the portion of the solution for the inversion do not deliver the full volume on account of the viscosity of the solution. These two factors offset about a half of the known error in the Herzfeld divisor and cause low results when a more nearly correct divisor is used.

Gravity solids and sucrose balances for factories reporting sucrose data are in Table 4. None of the factories has reported a negative undetermined loss of solids; an improvement over the two previous seasons. On the other hand, negative undetermined losses of sucrose appear in data for four factories, a larger number than in previous years. The increase is probably caused by errors in sucrose in commercial sugar associated with changes in the sucrose divisor, discussed in a preceding paragraph.

Sucrose data with true averages, for comparison with pol data in the large table, are in Table 5.

The difference between undetermined loss based on sucrose and the undetermined loss based on pol for factories included in Table 5 is .71. Taking into consideration the probable discrepancy in the average for sucrose in commercial sugar, the difference becomes .81. Applying this correction to the undetermined loss in the large table gives a corrected figure for all factories of .88. During the seven seasons in which the correction has been thus determined, it has varied between a maximum of .93 and a minimum of .81 with an average of .84. We can thus accept between .8 and .9 as the approximate correction to add to the undetermined loss when examining balances based on pol.

With reference to data submitted:

Pol data have been reported from all factories.

Sucrose in molasses has been reported from all factories for the first time.

Other sucrose data have been reported from 35 of the 38 factories.

Molasses weights have been reported from 32 factories and weights calculated from measurements from the remaining six. This is the first season that data on the quantity of molasses have been reported from all factories.

pH data for hot limed juice, clarified juice and syrup have been reported from all factories. This is the first season that these data have been complete.

Turbidity of clarified juice has been reported from 33 factories.

MILLING

Milling has attained a new high mark. For the first time the extraction is above 97.5, extraction ratio below 20, and milling loss below 2.5. Bagasse pol is considerably lower than in any previous season, while bagasse moisture equals the previous record made last season. Improvements in milling are reported from about two-thirds of the factories.

The trend has been toward better results during the past five or six years. This is the third successive season in which a new record has been made for milling loss, but the first season in which extraction has exceeded the record made in 1920. Decreases in cane pol, which amount to 1.22 since 1920, have made it more difficult to attain high extractions. Had cane pol remained as high as in 1920, without doubt the extraction record of that year would have been exceeded prior to this season.

The average grinding rate for mills now in operation has increased approximately half a ton. Averages in the large table for tons of cane ground per hour indicate an increase of .92, but these figures are misleading as the 1932 average has been increased by the omission of data from Olowalu, a factory with a low grinding rate which is no longer operated.

Data for imbibition per cent cane disclose a small trend toward an increase during the past four or five years, notwithstanding appreciable increases in grinding rate. An increase of .56 in imbibition this year brings the average to 33.75 per cent. While considerably lower than in some preceding years, this is the highest average since 1924.

The trend toward higher pressure continues. The average reported per foot of roller is now 70.8 tons, an increase of half a ton over last season. The total increase during the 11 seasons for which data have been compiled is 5.6 tons per foot of roller.

Additions to milling machinery consist of replacing two roller crushers with three roller units at Laupahoehoe and Waiakea. Improvements over last season in extraction amounting to .56 and .92 respectively have been realized. These increases are equivalent to a quarter of the increase in the average for extraction. On the other hand, suspending factory operations at Olowalu has made a reduction in the amount of milling machinery. As the extraction at Olowalu was higher than the extraction secured at Pioneer, where the cane is now ground, this has tended to depress the average extraction and thus has partially offset the influence of the additions to milling machinery on this average.

In summing up, reported data disclose two factors, higher grinding rate and lower pol in cane which have influenced extraction adversely, and three factors.

TABLE NO. 6—MILLING RESULTS

Showing the rank of the factories on the basis of milling loss.

Rank	1931 Rank	Factory	Milling Loss	Extraction Ratio	Extraction	Imbibition % Cane	Tonnage Ratio	Tonnage Fiber Ratio
1	1	Waimanalo	1.33	11.7	98.51	38.12	1.95	24.9
2	2	Hakalau	1.40	13.3	98.44	36.54	1.81	21.3
3	4	Wailuku	1.66	12.4	98.51	40.47	1.32	15.9
4	3	Onomea	1.66	15.1	98.25	36.20	2.22	25.7
5	7	Hilo	1.76	16.2	97.92	31.40	1.97	25.3
6	8	Oahu	1.86	13.8	98.42	34.84	1.84	21.2
7	23	Waialua	1.93	14.3	98.15	36.97	2.21	28.4
8	6	Ewa	1.99	14.1	98.13	38.51	1.60	21.2
9	11	McBryde	1.99	17.0	97.68	40.65	1.46	19.9
10	5	Honomu	2.04	18.7	97.81	39.65	1.51	17.7
11	15	Kohala (Hawi)	2.04	18.3	97.61	26.56	2.13	27.8
12	13	Pepeekeo	2.07	18.8	97.62	27.98	1.85	23.4
13	9	Paauhau	2.10	19.3	97.35	33.82	1.12	15.4
14	10	Kahuku	2.11	19.0	97.72	28.22	1.70	20.3
15	12	Haw. Sug	2.17	15.2	98.04	39.72	1.80	23.3
16	14	Pioneer	2.24	16.5	97.81	34.98	2.47	32.8
17	17	H. C. & S. Co.	2.25	15.5	97.96	37.69	1.74	23.4
18	19	Koloa	2.40	20.9	97.36	38.21	1.39	17.6
19	16	Maui Agr.	2.48	17.1	97.77	37.97	1.89	24.6
20	18	Hutchinson	2.50	21.2	97.58	33.09	1.93	21.9
21	26	Lihue	2.53	21.9	97.31	28.40	2.39	29.3
22	20	Waimea	2.55	18.4	97.68	36.31	1.66	20.8
23	29	Laupahoheoe	2.57	21.8	97.43	31.31	1.97	23.2
24	27	Olaa	2.59	22.8	97.08	29.19	2.45	31.3
25	31	Waiakea	2.65	23.3	97.00	36.11	1.92	24.8
26	24	Haw. Agr.	2.76	23.4	97.31	29.09	2.04	23.4
27	25	Hamakua	2.81	24.8	97.02	33.05	1.53	18.4
28	28	Kohala	2.89	25.7	96.92	30.96	1.67	20.1
29	21	Honolulu	2.91	20.6	97.58	35.32	1.53	18.0
30	22	Waianae	3.13	22.2	97.51	29.65	1.70	19.1
31	30	Kekaha	3.14	23.2	97.23	29.83	2.39	28.4
32	32	Kilauea	3.22	31.3	95.61	27.14	1.62	22.8
33	34	Kaiwiki	3.51	29.2	96.36	20.93	1.78	22.2
34	33	Makee	3.63	31.9	96.02	31.64	2.22	27.7
35	35	Honokaa	3.99	39.1	94.73	34.41	1.67	22.5
36	36	Kaeleku	4.10	36.2	95.02	37.18	1.82	25.0
37	38	Niulii	4.87	48.6	93.34	23.01	2.04	28.0
38	37	Union Mill	5.24	47.5	93.33	21.18	1.70	23.8

increased imbibition, heavier pressure and additions to milling machinery, which have had a favorable influence.

The purity difference between first expressed and mixed juice (Table 7) is 2.91. While this is .02 larger than last season, smaller differences have been recorded in but three previous seasons.

No factory has come particularly close to equalling previous records at individual factories in extraction, extraction ratio or milling loss, nor is the number of factories reporting over 98 extraction as large as in several previous seasons. The number reporting under 2.0 milling loss equals the previous record of 9 made last year.

The usual ranking of factories according to milling loss, with a summary of the more important milling figures, is in Table 6. A material improvement at Waialua has advanced this factory from 23 to 7. The improvement follows a decrease in grinding rate and heavier imbibition. Following the installation of new milling equipment, Waiakea and Laupahoehoe have each advanced 6 in relative rank. Lihue has advanced 5. Following an increase in grinding rate, Honolulu has dropped 8 in relative rank. Waianae also has dropped 8, and Honomu 5.

Boiling House Work

Marked improvements have been made in this department as well as in milling. As a result, new records have been established for final molasses purity and overall recovery, and the boiling house recovery is higher than in any year since Synopsis data have been reasonably complete.

Recoveries have been favored somewhat by an improvement over last season in juice purities, the improvement in the purity of the first expressed juice amounting to .39. While better than last season, juice purities are lower than in the two preceding years.

Clarification: Another factor contributing to higher recoveries this season is as unusually large increase in purity from mixed juice to syrup. Data in Table 7 indicate an improvement of .30 over last season. The average increase in purity, 1.66, was equalled in 1927, but with this exception it is considerably better than in any recent year. With the better purity increase in clarification, the improvement over last season in syrup purity is .64.

The decrease from 7.99 to 7.93 in the average pH of the hot limed juice is misleading, data for one large factory from which pH of the hot limed juice had not been reported previously having depressed the average to this extent. The average for the other factories is identical with the average of last season.

Averages for turbidity of clarified juice are also misleading. Although the average has decreased from 3.41 to 3.33, examination of data does not disclose a general tendency toward poorer turbidity. Including data from two factories from which turbidity had not been reported previously and excluding one factory previously included which did not report this year, together with much poorer turbidity reported from one large factory have depressed the average to a greater extent than the difference between averages for the two seasons. Averaging data from other factories reporting turbidity in both seasons indicates a small improve-

TABLE NO. 7

True averages of factories basing control on mixed juice.

	1927	1928	1929	1930	1931	1932
First Expressed Juice—						
Brix	17.17	17.45	17.76	17.36	17.57	16.74
Pol	14.74	15.08	15.40	15.04	15.13	14.48
Purity	85.84	86.41	86.69	86.68	86.10	86.47
"Java ratio"	81.7	81.6	82.1	81.5	81.8	82.0
Mixed Juice—						
Brix	12.88	13.04	13.29	12.98	13.13	12.75
Pol	10.67	10.89	11.15	10.87	10.93	10.65
Purity	82.88	83.47	83.89	83.73	83.21	83.56
Weight % cane	109.71	109.87	110.18	109.77	110.28	108.62
Extraction	97.23	97.24	97.28	97.25	97.36	97.49
Extraction ratio	22.1	22.1	21.7	21.8	21.2	20.6
Last Expressed Juice—						
Pol	1.88	1.94	1.99	1.94	2.01	1.84
Purity	67.76	68.39	68.73	68.54	68.19	67.71
Imbibition water % cane	32.04	31.99	32.44	32.15	32.23	32.59
Syrup—						
Brix	62.91	63.05	63.38	64.09	64.16	64.38
Purity	84.54	84.86	85.24	85.17	84.57	85.22
Increase in purity	1.66	1.39	1.35	1.44	1.36	1.66
Lbs. avail. CaO per ton cane	1.52	1.46	1.38	1.30	1.37	1.23
Filter Cake—						
Pol	2.22	2.34	2.27	1.82	1.65	1.20
Weight % cane	2.67	2.87	2.87	2.96	2.99	3.23
Pol % pol of cane	0.49	0.55	0.52	0.44	0.40	0.33

ment over last year, with an equal number of factories reporting better and poorer turbidities.

The amount of lime has decreased. The average, expressed as pounds available CaO per ton cane, is 1.25, against 1.37 in 1931 and 1.32 in 1930.

Filtration: Losses in filter cake have been reduced materially, an increase in the quantity of press cake having been much more than offset by a large decrease in pol. The loss in press cake per cent pol in cane (Table 7) has been reduced from .40 to .33, the lowest figure since 1921.

The improvement may be credited to Oliver-Campbell filters. If the factories using vacuum filters had reported the same loss in filter cake as last year, instead of the large reduction, there would have been a small increase in the average loss in filter cake. The increase in the quantity of filter cake is likewise attributable to this equipment.

Handling settlings with filters of the vacuum drum type is a comparatively recent innovation. Its practicability was first demonstrated on a factory scale at Oahu Sugar Company in 1926 by the late Mr. John F. Borden, a man who contributed much to improvements in the art of filtration. With further improvements by Mr. R. C. Campbell, which include modifications in design and utilizing screened bagasse as a filter aid, equipment is now available which will filter settlings at a high capacity and with which the loss in filter cake can be reduced to a very low point. While this has entailed some sacrifice in the clearness of the filtrate, in view of improvements made in the comparatively short period of seven

years, it would be rash to predict that this deficiency will not be ameliorated or corrected.

Filters of this type are now installed in six Hawaiian factories. The original installations at Oahu and Olaa were Olivers. At Oahu, screens were substituted for cloth in 1929. At Olaa, the original drums were replaced with Oliver-Campbell drums and bagasse sifting equipment was installed during the 1931 season. Installations at the other four factories are Oliver-Campbell equipment. At Kekaha, one unit was installed during the 1931 season and a second unit during 1932. At Koloa, a filter was installed prior to the 1932 season; at Ewa and Honokaa, filters were installed during the 1932 season. Material reductions in filter cake loss over previous practice have been realized at all of these factories except Honokaa, and at this factory the loss was materially reduced while the filter was in operation.

In addition to reducing the loss in filter cake, the Oliver-Campbell equipment should render it practicable to screen the cush-cush from the mixed juice thoroughly. This should be a material advantage, for allowing considerable amounts of cush-cush to pass through the clarification for the purpose of making the settlings filterable is a decidedly undesirable feature of our present practice.

Evaporation: The average density of the syrup has increased from 64.15 to 64.64, the highest figure on record. No additions to evaporator equipment have been reported. With a higher grinding rate, an increase in the percentage of mixed juice on cane, and the lowest mixed juice density on record, the increase in the calculated amount of water evaporated per hour is 3.1 per cent greater than last season.

Commercial Sugar: The pol of the sugar has increased for the thirteenth successive season, bringing the average to 97.76. The increase has been principally among factories in the Crockett group, the average for these factories being 97.86 against 97.78 last year. The average pol for other factories is 96.97 against 96.96.

The average deterioration factor has reached a new low point, .227. Four factories, however, report deterioration factors in excess of .25, an increase of one over last season.

Final Molasses: The new record for final molasses purity is 35.90, an improvement of .42 over the previous record of last season. A decrease in the purity of the low grade sugar has accompanied the improvement in molasses purity. We might note that in visualizing the effect of decreases in molasses purity, we may consider that under average conditions a decrease of 3 in molasses purity corresponds to an increase of 1 per cent or slightly more in sugar production.

Decreases in molasses purity are reported from 23 factories and increases from 14.

Koloa leads with 32.62 purity. This, however, does not equal the record for an individual factory of 31.81 made at Kahuku in 1927.

Factories are listed below in the order of the final molasses purity together with the relative rank in 1931.

GRAVITY PURITY FINAL MOLASSES

Rank 1932	Rank 1931	Factory	Gravity Purity	Rank 1932	Rank 1931	Factory	Gravity Purity
1	4	Koloa	32.62	20	26	Makee	36.50
2	1	Kahuku	33.13	21	15	Maui Agr.	36.66
3	2	Hamakua	33.37	22	24	Hilo	36.7
4	6	McBryde	33.50	23	34	Olaa	36.77
5	3	Ewa	33.75	24	23	Onomea	36.79
6	11	Laupahoehoe	33.80	25	18	Waiakea	36.95
7	9	Oahu	34.07	26	19	H. C. & S.	37.19
8	5	Haw. Sugar	34.15	27	35	Kilauea	37.38
9	10	Hutchinson	34.21	28	31	Kohala (Hawi)	37.53
10	17	Lihue	34.3	29	30	Kekaha	37.65
11	12	Pepeekeo	34.43	30	29	Wailuku	37.83
12	7	Pioneer	34.48	31	27	Kohala	38.01
13	13	Hakalau	35.48	32	25	Honokaa	38.35
14	22	Waialua	35.62	33	38	Union Mill	38.64
15	14	Honomu	35.90	34	32	Kaeleku	39.55
16	16	Waimanalo	35.90	35	37	Niulii	41.26
17	8	Waianae	35.91	36	33	Paauhau	41.29
18	21	Honolulu	36.10	37	36	Kaiwiki	41.43
19	20	Haw. Agr.	36.45	38	..	Waimea	42.12

Changes of five places or more in relative rank are as follows: Increases, Olaa 11, Waialua 8, Kilauea 8, Lihue 7, Makee 6, Laupahoehoe 5, and Union Mill 5, and decreases, Waianae 9, H. C. and S. 7, Honokaa 7, Waiakea 7, Maui 6, and Pioneer 5.

At Union Mill new crystallizers and centrifugals have been installed and the low grade pan has been rebuilt. A reduction of 6.42 in molasses purity has been realized. This is the largest improvement at any factory. Improvements of 2.83 at Olaa and 1.60 at Hawi have also been realized, following additions to the low grade centrifugal equipment.

Recovery

As noted in a previous paragraph, the overall recovery, 89.82, is a new record. It is .49 higher than the previous record made in 1930 and .65 higher than the recovery of last year.

It is quite probable that the boiling house recovery also is actually higher than has been attained previously, although the average, 92.09, does not equal figures recorded for 1907 and 1909. If data had been reported from all factories, or indeed, if chemical control had then been as reliable as at present, there is little doubt but that lower averages than the present boiling house recovery would be recorded for these years.

Improvements over last season in recovery are due in part to better juice purity. This accounts for .29 of the .65 increase in overall recovery. The difference, .36, is equivalent to a .44 per cent improvement over the recovery of last year, attributable to better results in the factory. Better purity increase in clarification and lower molasses purity account for the greater part of the improvement, with higher extraction, lower loss in filter cake and lower undetermined loss as contributing factors. These have been offset to a slight extent by the increase in the pol of the sugar.

Calculations based on quality ratio, in which yields of sugar per cent cane corresponding to quality ratio are compared with sugar production per cent cane,

indicate about the same percentage of improvement attributable to better results in the factory. In 1931 sugar production was 100.02 per cent of that indicated by quality ratio. This year production was 100.53 per cent, an improvement of .51 per cent against the .44 per cent indicated by the usual control figures.

In the Synopsis of 20 years ago, Noel Deerr remarked that—"though we obtain here over all a larger recovery than elsewhere, it is still possible to increase this margin further, and to add, I believe, 5 per cent to the output from a given weight of cane." If we modify his wording to meet the lower quality of cane that has accompanied the higher cane yields which we now enjoy, we might count him as having predicted a 5 per cent increase in the output from a given weight of sugar in the cane. Thus construed, the prediction has been liberally fulfilled, for this year the output from a given weight of sugar in the cane is 5.73 per cent greater than when he made his forecast. This has been accomplished in spite of handicaps imposed by decreases in cane pol and in juice purity. Were we handling cane of the same characteristics as the cane of 20 years ago, the predicted increase would now be exceeded by a considerably wider margin.

Calculations in this Synopsis have been made by Mr. Brodie, assisted by Mr. Ashton and others of this department.

TABLE NO. 8

COMPARISON OF ACTUAL AND THEORETICAL RECOVERIES

Recovery % Calculated Recovery *					Recovery % Recovery Indicated by "Sugar Ratio" †	
Rank	Factory	Milling	Boiling House	Over All	Rank	Over All
1	Kahuku	97.72	104.86	102.77	1	103.61
2	Hamakua	97.02	104.04	101.45	12	99.93
3	Oahu	98.42	102.70	101.36	2	101.73
4	Koloa	97.36	103.34	101.01	8	100.43
5	Hutchinson	97.58	102.93	100.76	9	100.15
6	Haw. Sug	98.04	102.44	100.71	3	101.14
7	Honomu	97.81	102.61	100.66	7	100.44
8	Hakalau	98.44	101.86	100.63	6	100.50
9	Ewa	98.13	102.22	100.56	4	100.89
10	Waimanalo	98.51	101.20	99.97	19	98.91
11	McBryde	97.68	101.97	99.96	10	100.11
12	Onomea	98.25	101.23	99.77	5	100.61
13	Lihue	97.31	101.85	99.50	14	99.72
14	Maui Agr	97.77	101.33	99.49	13	99.82
15	Pepeekeo	97.62	101.66	99.44	15	99.48
16	Waialua	98.15	100.97	99.36	11	100.10
17	Waiakea	97.00	101.79	99.17	21	98.57
18	Kohala (Hawi)	97.61	100.17	99.15	22	98.03
19	Laupahoehoe	97.43	101.39	99.00	18	99.04
20	Wailuku	98.51	100.02	98.78	16	99.46
21	Pioneer	97.81	100.52	98.64	20	98.70
22	H. C. & S. Co	97.96	100.33	98.57	17	99.17
23	Kaeleku	95.02	102.60	97.90	25	97.71
24	Hilo	97.92	99.55	97.76	27	97.56
25	Haw. Agr	97.31	99.84	97.46	24	97.81
26	Waianae	97.51	99.56	97.31	23	97.83
27	Olaa	97.08	99.61	97.13	26	97.57
28	Makee	96.02	100.34	96.91	31	96.56
29	Honolulu	97.58	97.98	95.83	29	96.93
30	Kohala	96.92	98.53	95.79	30	96.60
31	Kekaha	97.23	98.07	95.71	28	97.00
32	Kilauea	95.61	98.94	95.07	32	94.48
33	Honokaa	94.73	99.64	94.90	33	94.44
34	Paauhau	97.35	96.80	94.60	34	94.34
35	Kaiwiki	96.36	96.91	93.67	35	93.45
36	Union Mill	93.33	99.45	93.14	36	93.43
37	Waimea	97.68	94.00	92.11	37	92.22
38	Niulii	93.34	95.47	89.57	38	88.90

* Factories are arranged in the order of the ratio of their recovery to that calculated on the basis of 100% extraction, 37.5 gravity purity molasses and no other losses.

† The basis of this calculation is 98 extraction, syrup purity one less than the apparent purity of the first expressed juice, sugar purity 98, gravity purity of molasses 33.33 and no other losses.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 21, 1932, TO DECEMBER 15, 1932

Date	Per Pound	Per Ton	Remarks
Sept. 21, 1932	3.15¢	$63.00	Porto Ricos.
" 23	3.14	62.80	Cubas.
" 27	3.135	62.70	Philippines, 3.13; Cubas, 3.14.
" 28	3.145	62.90	Porto Ricos, 3.14, 3.15.
" 29	3.18	63.60	Philippines.
Oct. 1	3.16	63.20	
" 4	3.15	63.00	Cubas.
" 5	3.14	62.80	Cubas.
" 7	3.16	63.20	Porto Ricos.
" 10	3.18	63.60	Porto Ricos.
" 13	3.20	64.00	Cubas, Porto Ricos.
" 14	3.175	63.50	Cubas, 3.17, 3.18.
" 17	3.155	63.10	Cubas, 3.15, 3.16.
" 21	3.13	62.60	Porto Ricos, 3.14; Cubas, 3.12.
" 24	3.12	62.40	Cubas.
" 25	3.10	62.00	Porto Ricos, Cubas.
" 26	3.085	61.70	Cubas, 3.08, 3.09.
" 27	3.07	61.40	Cubas.
" 28	3.05	61.00	Cubas, 3.04, 3.05, 3.06.
Nov. 2	3.10	62.00	Porto Ricos, Philippines, Cubas.
" 4	3.12	62.40	Cubas.
" 12	3.15	63.00	Porto Ricos, Philippines.
" 14	3.13	62.60	Cubas.
" 15	3.11	62.20	Cubas, 3.10, 3.12.
" 16	3.10	62.00	Cubas.
" 18	3.08	61.60	Cubas.
" 22	3.015	60.30	Cubas, 3.03; Philippines, 3.00.
" 25	3.00	60.00	Cubas.
" 28	2.95	59.00	Cubas.
" 29	2.92	58.40	Cubas.
" 30	2.885	57.70	Philippines, 2.90; Cubas, 2.87.
Dec. 2	2.85	57.00	Cubas.
" 8	2.88	57.60	Porto Ricos.
" 9	2.90	58.00	Cubas.
" 13	2.89	57.80	Cubas, 2.88, 2.90.
" 14	2.85	57.00	Cubas.
" 15	2.82	56.40	Cubas.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVII SECOND QUARTER, 1933 No. 2

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Poison Bait for Armyworms and Cutworms:

An account of an improved poison bait for use against armyworms and cutworms on plantations subject to heavy rains is given.

Rate of Cane and Sugar Formation in Cane Crop:

This short note presents our latest views on the rate of cane and sucrose formation in a field of cane. It is pointed out that the highest rate of sucrose storage follows very closely upon the highest rate of cane formation, which latter, as we all know, occurs between the age of six to twelve months.

Water-Stage Register for Plantation Field Ditches:

A simple and inexpensive water-stage register designed and constructed by the agricultural department of the Station is described. Since the preparation of this paper, thirty-four instruments have been manufactured and delivered to plantations at cost. Although similar in general plan, the instruments are somewhat simpler than the model illustrated.

The performance of these devices is being watched with interest.

Use of Thallium Torpedoes:

Some further evidence is given that thallium torpedoes treated with corn oil are attractive to rats.

The bad odor sometimes developing in the torpedoes is thought to be due to excessive direct heat to the paraffin bath during dipping.

Weather Charts for Plantation Use:

In this article, one of our plantation managers details how he keeps records of the weather conditions affecting his crops, and sets forth various ways in which the

recorded information can be used to greatest advantage in directing plantation policies.

Some Physical Constants for Cane Soils:

Although it has long been known that the physical and chemical nature of a soil depends largely upon the conditions of weathering under which the soil is formed, local work in this field has been meager.

The present paper reports the value of six physical constants and the results of two chemical determinations for seventeen soils secured from Hawaii and Maui. Some of the results are presented in graphical form.

It is evident that the highly productive soils of Maui are characterized by high apparent densities, low ignition losses and high ratios of SiO_2 to Al_2O_3 and R_2O_3 in the colloidal material. Soils from the Hamakua coast carry high percentages of material which may be lost on ignition and relatively high percentages of colloidal organic matter. As is well known, these soils fix P_2O_5 markedly. The soils from Kohala form a third group, which is more similar in its properties to the Maui soils than to the other soils from Hawaii.

Soils from certain "growth failure" areas are similar to near-by productive soil in all measured characteristics.

Strengthening Lime Mortar by Addition of Molasses:

It has long been known that the addition of sugar or molasses to lime mortar will increase the strength of the mortar. The investigation here reported presents definite data on the beneficial results obtained by adding molasses to lime mortar.

Poison Bait for Armyworms and Cutworms

As a supplement to the standard arsenical dust for use against armyworms as described on pages 5-6 of *The Hawaiian Planters' Record* for the first quarter of 1933, the following bait has been found to be an improvement over former baits used:

10 pounds bagasse
20 pounds molasses
1 pound white arsenic
½ pound casein (Kayso)
2 quarts water.

Before the ingredients are mixed together the arsenic is first stirred into the molasses.

The new feature of this bait over others formerly used in Hawaii is the inclusion of casein in the mixture. This has been added at the suggestion of Dr. F. E. Hance, chief chemist of this Experiment Station. The casein greatly improves the coherence of the particles composing the mixture and adds to its life very considerably by preventing breakage, scattering and washing away when beaten upon by drenching showers of rain. Raymond Conant, of Olaa Sugar Company, Ltd., prepared such a bait and tested it at the Mountain View section of the plantation with entirely satisfactory results.

In armyworm warfare we now have two poison methods of control which should not be confused. The poison dust mixtures, made and applied in accordance with the instructions given in the last issue of the *Record* will continue to be the most generally used and most satisfactory in combating nearly all outbreaks of armyworms. This applies especially to the nutgrass armyworm *Spodoptera mauritia*. However, there will be times when the other armyworm, *Cirphis unipuncta*, will become destructive, especially during periods of heavy rain. The bait above described should prove useful against this insect, particularly because many of them usually occur on the ground during the daytime. This bait will also be of importance in controlling certain cutworms in gardens.

C. E. P.

Rate of Cane and Sugar Formation in a Cane Crop

By U. K. Das

Following a recent request, I have herein attempted to set down our ideas on "how cane and sugar are formed as the crop proceeds." Though the data particularly relate to H 109, it is believed that the general consideration will apply equally well to other varieties.

Generally a crop is complex in its composition. At any period, it contains stalks of various ages, each age group forming cane and sugar at different rates. For the sake of clarity, then, we may omit for the moment the discussion of what happens to a crop, and take up the question of what happens to a single joint of cane, which is the most readily discernible unit of a cane crop.

A joint that has just completed its length (and is almost completely developed) contains little or no sugar. Under ordinary conditions, the sugar storage in that particular joint must follow very readily the completion of vegetative growth, for we find that by the time the leaf attached to that joint has dried up or dropped off, that joint has reached a certain state of maturity. (Our present information is that this joint may accumulate a little more sugar as time goes on. But this amount will be only a small fraction of all the sugar that is in that joint.) In support of this statement we may cite the numerous joint-to-joint analyses of Brix that we have made in the past few months, of which a few representative data are shown in the accompanying illustrations.

If we assume the longevity of a leaf from the time it fully develops to yellowing or dying off to be about two to three months, then, we should expect the storage of sucrose in a particular joint to be more or less completed in about two to three months after it has been formed.

From considerations of a single joint of cane, we may now proceed to the consideration of a single stalk of cane. As we all know, a stalk of cane grows at varying rates depending on its age. Its rate of growth is also influenced by the environmental condition of weather and culture. But keeping in mind what we said about a single joint, we may conclude that the rate of sucrose formation will follow closely the rate of cane formation—lagging behind by two to three months. Several years ago, the writer established that independently of other factors, and under optimum cultural conditions, the rate of length growth in an average primary stalk of H 109 cane was the highest between 6 to 10 months of age. We would then expect the rate of sugar formation also to be highest between, say, 8 to 12 months of age.

From consideration of a single stalk of cane, we may now take up the question of a crop of cane. As has been said previously, a crop at any stage of development is complex in its composition. An estimation of rate of sucrose formation in a cane crop is, therefore, a little more complicated. But we may again apply our analogy and say that the highest rate of sucrose accumulation will follow with due

lag the highest rate of cane formation. Fortunately, for us, we have some data from Waipio Experiment E to substantiate our claims.

In this experiment cane was planted in the different seasons and aliquots of the area harvested at different ages. The average rate of cane formation and sucrose storage was, then, calculated for various ages.

The data are presented graphically in Fig. 4. There we see that the rate of increase in cane tonnage per month was highest between 6 to 9 months, and that the monthly rate of increase in tons sugar per acre was highest between 9 to 12 months of age. In other words, the highest rate of sugar accumulation lagged about three months behind the highest rate of cane formation. We therefore conclude that (contrary to popular belief) sucrose storage goes on at the maximum rate soon after the cane growth has reached the maximum; in other words, in the earlier months of a cane crop.

In all these discussions, we have considered the rate of sucrose storage only and not the total amount of sugar stored. This latter will generally increase with the increase in tonnage of a cane crop. Data from Waipio Experiment E show that this maximum amount is reached for plant H 109 cane at about 24 months of age.

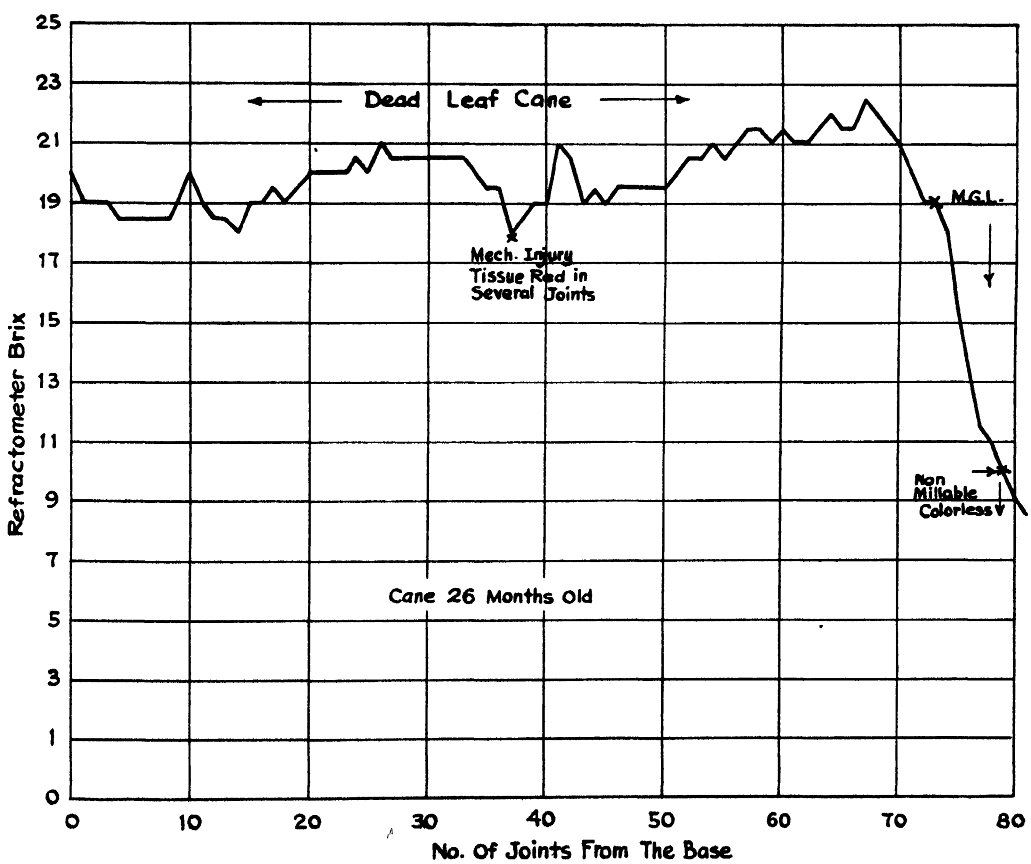


Fig. 1

(For legend, see Fig. 3)

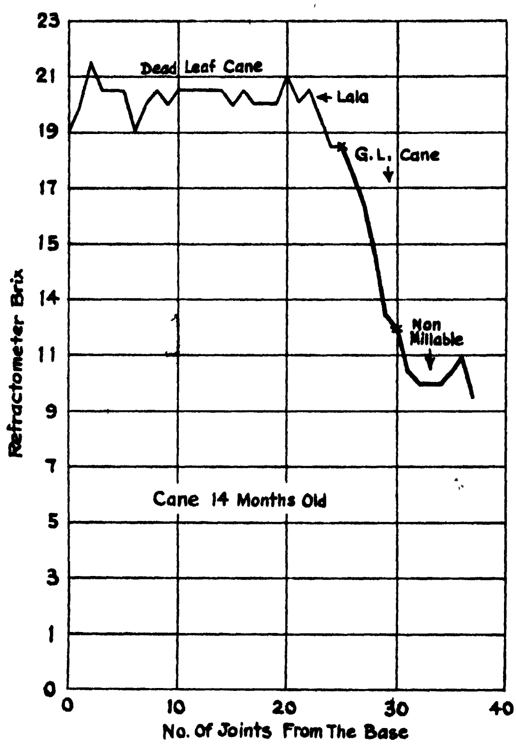


Fig. 2

(For legend, see Fig. 3)

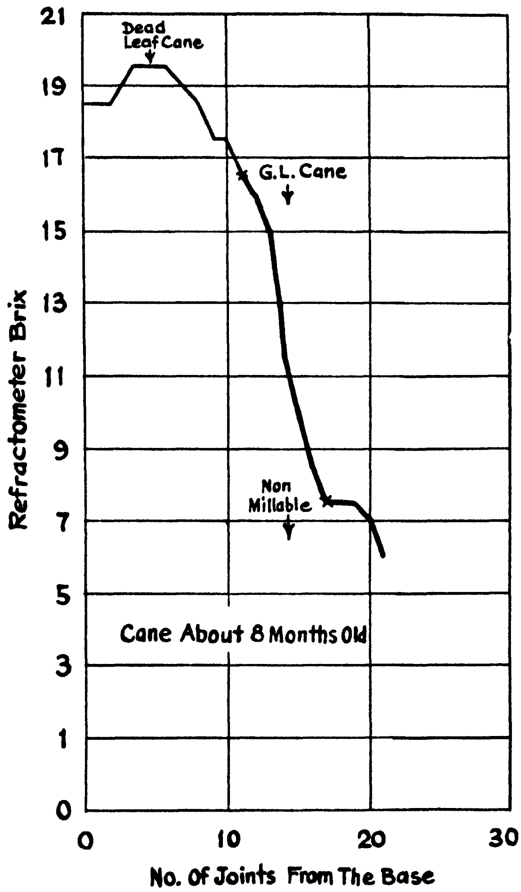


Fig. 3

In Figs. 1, 2, and 3 it will be observed that the recently formed joints just below the M. G. L. (millable green leaf) section have almost as much Brix as the joints near the bottom, which latter were formed weeks and months before.

The joints in this M. G. L. section are, however, still very immature. As there is only an interval of two or three months separating the M. G. L. section from the top end of the dead leaf section, it is easily concluded that the rate of sucrose accumulation is very rapid in this M. G. L. section, which has just passed through its period of the most active vegetative growth.

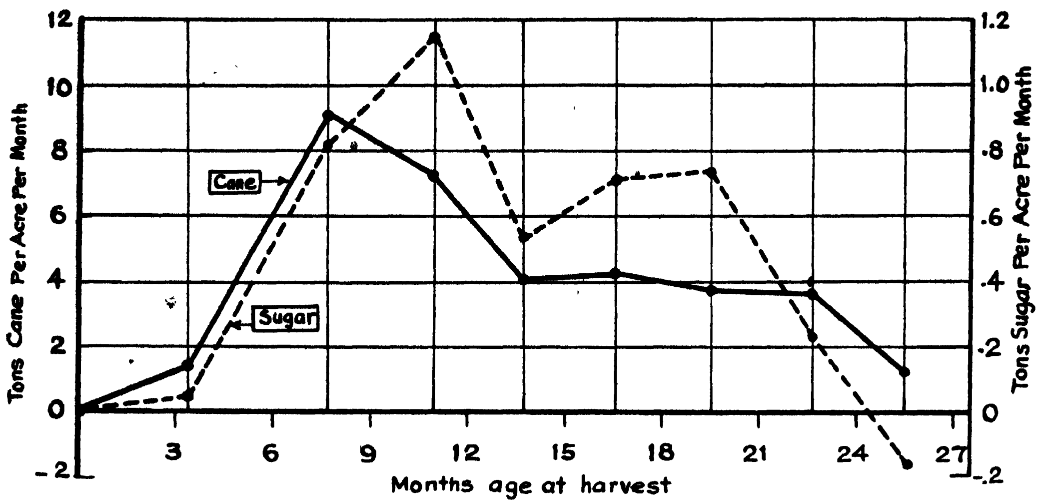


Fig. 4

The point of interest in this figure is that the rate of cane and sugar formation is very slow at first, then the rate rises very rapidly, to be followed by rapid decline. It shows that between 9 and 12 months of age the average crop in this experiment was making sugar at the rate of 1.2 tons per month, while between 6 and 9 months the average crop was making cane at the rate of 9 tons per acre per month.

The practical implication of these great variations in rate of growth at different ages must be clearly borne in mind in any progressive cultural policy on a plantation.

An Inexpensive Water Stage Register for Use on Plantation Field Ditches

By H. A. Wadsworth

A locally designed water stage register has been built for use on field ditches where the necessary precision of measurement does not justify the significant investment represented by the installation of one of the instruments now on the market. Since any water-measuring structure operates at low efficiency unless equipped with some form of recorder, the need for an inexpensive instrument for this purpose has long been apparent.

For two years the Experiment Station, H. S. P. A., in cooperation with the Physics Department of the University of Hawaii, has been developing such a device. The model which was exhibited during the last annual meeting of the Hawaiian Sugar Planters' Association employs no untried principles in instruments of this sort; it is simple, sturdy, inexpensively built, and promises an accuracy of record which is quite in line with the requirements of field measurement.

Like some devices of the sort, the record paper is used to cover a cylindrical

drum which rotates in its bearings under the action of a float riding in a properly located stilling well. The pencil moves along this drum under the action of a falling weight and under the time-control of a cheap clock. The clock simply acts as a brake regulating the speed of the pencil but does not drive it in any sense.

A cheap, readily replaceable clock has purposely been selected, it being thought that money for clock repairs might be better spent in the purchase of a new clock than in trying to repair an old one. Any eight-day clock, particularly a compact, eight-day alarm clock, may be used. The clock is attached to the bed plate by two thumb screws, which permit prompt replacement. A cheap clock of German manufacture has given satisfactory service for more than twenty weeks without attention. The clock costs $2.50.

The accompanying illustrations show the set-up from three points of view.

The instrument illustrated has been in field use on a Maui plantation since its exhibition last winter. In a letter under date of April 17, 1933, the manager of that plantation says:

> From all indications the instrument appears to be quite satisfactory for plantation flow measurements. It has run continuously since being set up in the field on December 23, 1932. An examination of the charts shows the time and gage height to be very close to the correct spot at the end of a week's run.

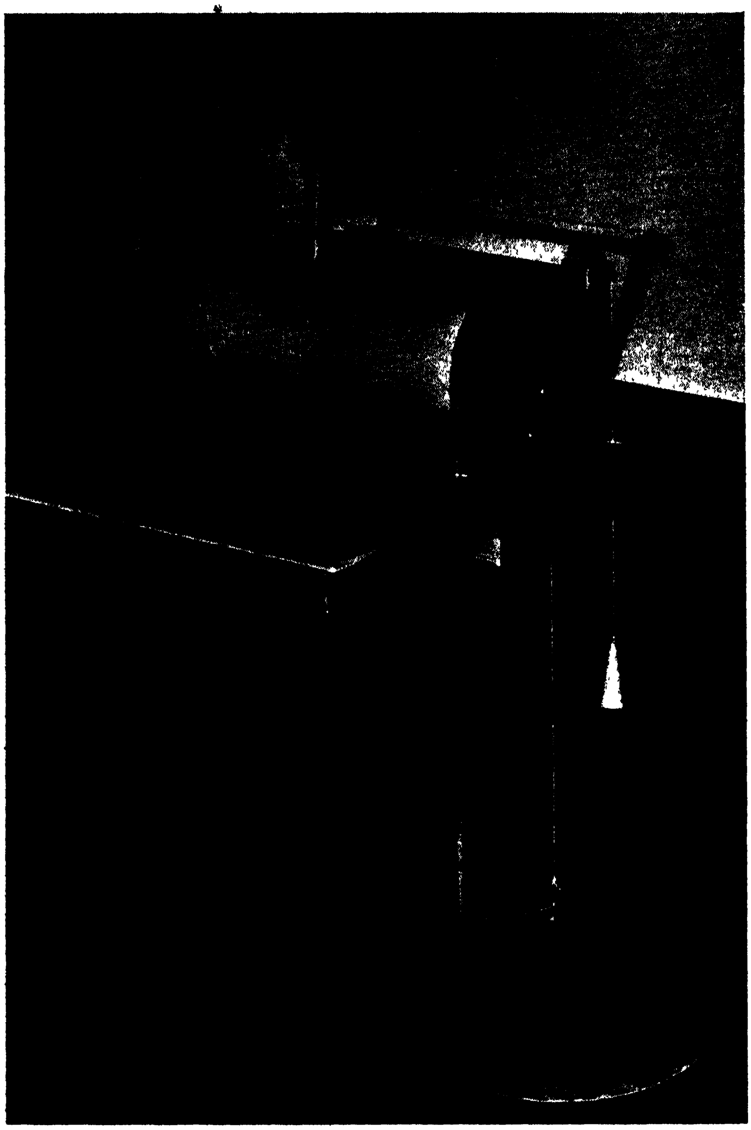
Present plans call for a minor modification in design. This involves installing a double pulley on the float end of the drum in order that the device may record in either a 1:1 ratio or 1:2 ratio. When the larger pulley is used, a head fluctuation of two feet may be accommodated with a single revolution of the drum.

Two plans have been proposed with respect to the construction of the instruments which may be needed. One of these involves their construction in plantation shops by plantation employees. In the furtherance of this scheme the Experiment Station stands ready to extend whatever aid it may in the preparation of working drawings and in lending for short periods the working model for replication.

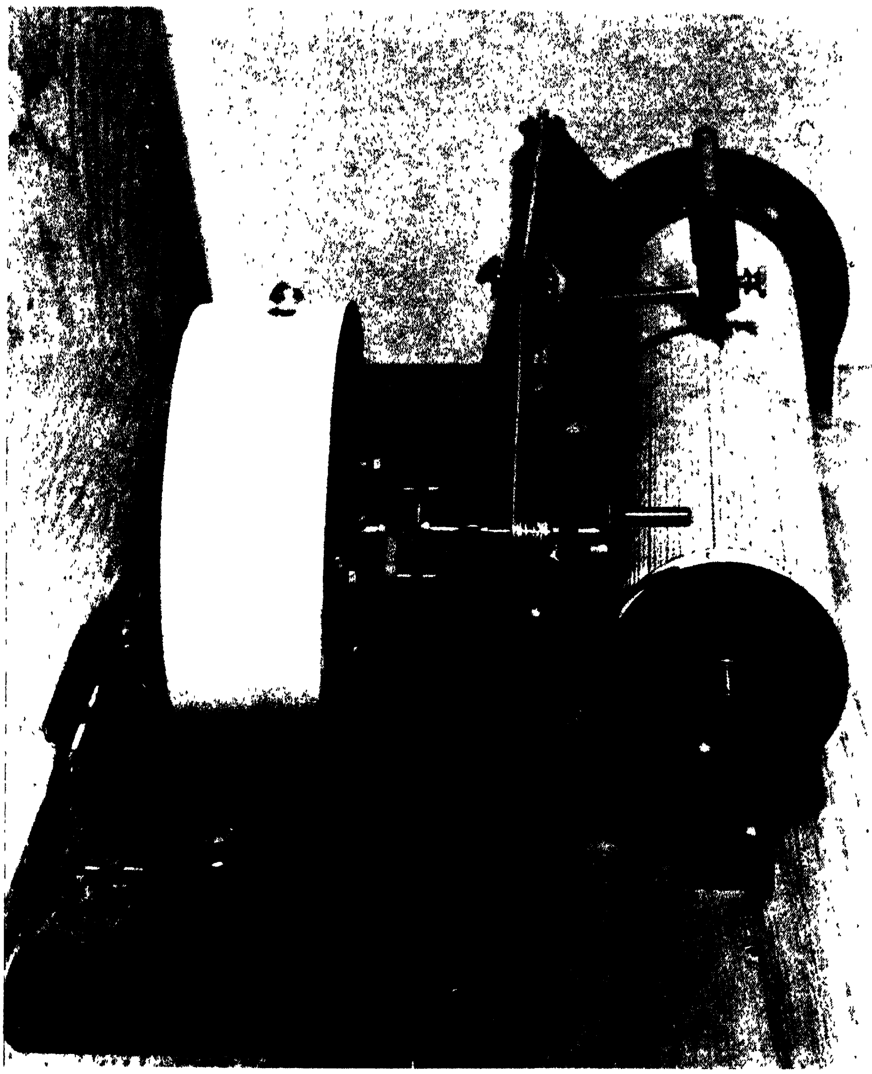
The other possibility involves the construction of the instruments in Honolulu under the supervision of the Experiment Station, and their subsequent distribution to interested plantations or agencies at cost. This scheme has the advantage of supplying uniform instruments as well as a source for standard replacement parts. Moreover, certain economies may be effected by production in numbers. Rough brass castings in certain parts would greatly lower the price if enough instruments were ordered to justify the patterns.

Preliminary cost figures, based upon the assumption that castings are to be used, indicate that the completed device will cost about $32.50 if made in Honolulu and distributed at cost. This charge includes material as well as the prorated charge for the patterns and payment for the time of the instrument maker in assembling. It should be said that greatest precision is required in at least two operations in the construction.

Some of these instruments are now being made on orders from plantations.



General view of the original model of the locally built water stage register showing float and counterpoises.



Detail of clock end of the register. Note that the pencil is drawn across the drum by the falling weight. The clock regulates the rate of the pencil's motion, but does not drive it.

Some Notes on the Use of Thallium Torpedoes

By R. E. Doty

A number of corn oil-paraffin torpedoes were checked against straight paraffin torpedoes at the Waipio substation recently. The corn oil-paraffin torpedoes were placed alternating with the straight paraffin torpedoes, each spaced some 8 to 15 feet from any other, along the edge of big cane. In some cases they were placed close to the base of fence posts, where they could be located easily.

To facilitate the counting and recording, these torpedoes were placed in groups of 20 of each kind. Ten of these groups were put out at one time, making a total of 200 of each kind in a series. Three such series were placed and gathered up again at the end of 36 to 40 hours.

The summary of these results are given herewith:

	No. Laid Out	No. Recovered	No. Nibbled	No. Taken Up
	Feb. 2, 1933			Feb. 4, 1933
Paraffin torpedoes	200	184	4	12
Corn oil-paraffin	200	115	21	64
	Feb. 6, 1933			Feb. 8, 1933
Paraffin torpedoes	194	162	11	21
Corn oil-paraffin	199	61	62	76
	Feb. 8, 1933			Feb. 10, 1933
Paraffin torpedoes	200	183	11	6
Corn oil-paraffin	200	97	77	26
Totals—Paraffin torpedoes	594	529	26	39
Corn oil-paraffin	599	273	160	166

It should be noted here that there were very few rats throughout most of the area used in this test. The area along the algaroba grove appeared to be thickly infested.

There was a total of only 39 straight paraffin torpedoes taken compared with 166 corn oil-paraffin torpedoes taken. This furnishes some additional data that corn oil lures the rats to the poison bait.

Notes from Kauai

C. C. Barnum reports that there were a number of cases where the rats were not taking the bait as formerly. Other complaints stated that the torpedoes had a bad odor and ceased to be as attractive as before. The difficulty was traced to burned paraffin which had been decomposed by excessive direct heat.

Paraffin melted over an open fire often becomes overheated to the point of smoking. In this case the paraffin breaks down, becomes yellowish in color and develops a bad odor and is apparently unpalatable to the rodents.

This condition may be overcome by melting in a water bath. Straight water at boiling is not quite hot enough if the dipping of torpedoes is proceeding rapidly. Dr. F. E. Hance recommends that this feature may be overcome by using a mixture of water and commercial radiator glycerine in proportions ranging from one part of glycerine to three parts of tap water up to 3 parts of glycerine to 1 part of water. A temperature of approximately 125° C may be obtained with the mixture of 3 parts of glycerine to 1 part of water. A predetermined mark should be made on the side of the container and water should be added at intervals to bring the level of the bath up to this mark. This solution will last indefinitely if this procedure is followed.

The amount of corn oil in the dipping mixture should not exceed more than 25 per cent by weight, or the paraffin will not harden sufficiently to be waterproof.

Considerable difficulty is being experienced with ants and cockroaches eating holes into the torpedoes. In this case it would seem advisable to materially reduce the amount of corn oil in the mixture or perhaps dip in pure paraffin and then spray corn oil on the torpedoes with a flit gun, as has been done at Honokaa Sugar Company and Hutchinson Sugar Plantation Company.

Weather Charts for Plantation Use

By W. L. S. Williams
Manager, Waiakea Mill Company

Importance of Weather Factors on Yield

It has always been recognized that the weather plays a very large part in the production of crops, but just how large this part really is has probably not been fully realized up to this time. Das* has shown that at Pepeekeo fully 80 per cent of the variations in yield from year to year can be attributed to variations in weather conditions. Here at Waiakea, we feel that weather exerts as much, and probably even a greater, influence on yields.

For many years past, all plantations have kept faithful records of rainfall, but it was only five or six years ago that the tremendous influence of slight changes in temperature was first recognized, and it is only within the past year or two that any marked attention has been paid to the factor of sunlight. In certain districts, the velocity and direction of the wind will also be a factor which must not be overlooked. The studies made by Das, first at Pepeekeo and later at Ewa and Honokaa, have been outstanding, and have led us, at Waiakea, to make a small beginning in attempting to reduce the main weather factors to numerical indices which can be graphically shown in chart form.

* Das, U. K. 1932. A Further Study of the Influence of Weather on Yield. *The Hawaiian Planters' Record,* Vol. XXXVI, No. 1, pp. 40-59.

We all recognize that good weather assists in crop production while bad weather retards our field work. We need warmth and sunshine to start a young crop on its way. We like to see heavy rains well distributed throughout the summer so that the year-old cane will make a vigorous growth. We want dry, sunny weather shortly before and during harvesting to improve juice quality. We all talk about the weather, and when two plantation men meet it is usually one of the first topics of conversation. But aside from keeping rainfall records and possibly noting the maximum temperatures each day, very few of us have really kept any definite weather records in a form readily available for comparison with previous years or the average of past years' observations.

It will be said that there is little profit in keeping definite weather records, as climatic conditions are beyond our control and charting the weather will not improve conditions in any way. We believe that weather data are fully as important as data on field areas. Our acreage is just as much beyond our control as is the weather, and various parts of any plantation probably vary as much over and under the average as weather conditions depart from normal from year to year. Yet we all keep careful and detailed account of our crop areas, express our yields in terms of tons of cane and sugar per acre, and feel that we would be entirely at sea if we did not have accurate maps of our plantation fields. In time, we believe, those responsible for the efficient operation of our plantation properties will feel the need of complete weather data and charts as much as they now require tabulations of field areas, maps and soil surveys, both for the operation of the individual plantations and also for the intelligent comparison of the results obtained on one plantation with the costs and yields on another.

Without definite weather data and charts, our conception of the weather will be largely a matter of personal opinion, and opinion is largely influenced by recent events to the exclusion of those more remote. If we have had several weeks of dry, hot weather, we are very apt to exaggerate in our own minds and feel that we are being afflicted by a severe drought, while a month or so of wet weather will wipe all thought of the drought from mind and possibly lead us to assume an overconfident outlook. However, we usually are prone to exaggerate bad weather and feel this more keenly than good weather. When a drought comes along, we lay all the blame for poor yields to the bad weather, while the good yields caused by a period of good weather are very easily attributed to our improved varieties, better methods of cultivating and fertilizing, and more efficient management in general. If weather charts do nothing else, they will do away with personal opinion and permit of fairer comparisons, as well as give a very accurate indication of the trend of yields and the efficiency of cultivation on any plantation, and allow us to know definitely whether weather conditions on any crop have been above or below normal, thus acting as a check on crop estimates.

Measurement of Weather Factors

About six months ago, prompted by the work done by Das at the Experiment Station, we began collecting all available weather data at Waiakea, and have attempted to assemble these data in a fairly simple manner so that comparisons

could be made from year to year. Available rainfall records for one station went back to 1906, but this was at the mill and not representative. Our other two stations were established in 1914 at 600 and 1100 feet elevations. This gave us very complete rainfall data for 18 years. Maximum and minimum temperature records were started at our 600 foot station in 1928, and at the 25- and 1100-foot stations in 1932. As the observations at the 600-foot station were very uniformly the approximate average of the other two readings each month, we have used only the one reading for temperature. No correlation with Hilo observations has been possible on temperature, so no use could be made of the Hilo records, which go back many years, and we have only five years of temperature records on which to base our work.

No sunshine records have ever been kept at Waiakea, and for this important item we have to use the Hilo records, with an arbitrary correction factor applied, in an attempt to approximate our own conditions. With these very sketchy data available, it is manifestly impossible to obtain quantitative results, and all we have hoped for is to make a start which may later be improved as more data accumulate from year to year. In order to assist in eliminating some of the errors which naturally will be present in data of this kind, we set up a series of assumptions which have been used uniformly throughout the work. Using these assumptions and the average monthly rainfall, temperature and sunlight data available, we then calculated and charted a normal weather curve. Using the same assumptions and the monthly data for various crops, we next calculated and plotted the weather curve for each crop. A comparison of the *normal* with the *crop* curves would then tend to cancel errors in the assumptions and in the basic data, and we believe the work done and the methods employed will be of future benefit to us and may possibly be of interest to others.

Rainfall

At Waiakea the rainfall is so heavy, averaging almost 20 inches in some months and having exceeded 50 inches per month on certain occasions, that it is obvious that the total rainfall cannot be considered effective on the growth of crops. With young cane we have noted a decided advantage in starting under fairly dry conditions, and even year-old cane should not be expected to utilize anything like 50 inches of rain in 30 days. An experiment at the Makiki plots, where cane was given irrigation at the uniform rate of 16 inches per month, was designed to give the cane all the moisture it could absorb. Considering the porous nature of our soils, we have assumed that a 20-inch rainfall per month would be effective on cane nine months old or over, that is, after closing in. Prior to closing in, we have assumed that young growing cane could absorb increasing amounts from month to month, and have arbitrarily set 2 inches as the effective rainfall for the first month after harvesting or planting, increasing this to 3, 4, 6, 8, 10, 13, 16 and 20 inches for the second to ninth month, respectively.

Using either the effective rainfall limit as shown above or the actual rainfall figure, whichever is the smaller, we can then calculate the "effective acre inches" for any crop by multiplying the area under cultivation in any month by the effective

inches of rainfall for that month and accumulating these monthly figures from the start of the crop until harvest. For instance, if 300 acres of the 1933 crop are cut in January, 1933, and there are 18 inches of rainfall that month, the "effective acre inches" for the first area of the 1935 crop will be 300×2 or 600 acre inches, the additional 16 inches being considered not effective. Similarly, if another 300 acres is cut in February, and rainfall is 12 inches that month, the "effective acre inches" for February will be (300×2)+(300×3) or 1500 and the "effective acre inches" to the end of February will be 1500+600 or 2100.

It has been pointed out by Das that the effective limit of rainfall will vary, depending on the temperature, sunlight and wind movement, but considerations of this type introduce so many complications and the method herein outlined is so rough in any case, that these effects must be considered unavoidable errors and within the limit of error of the whole system.

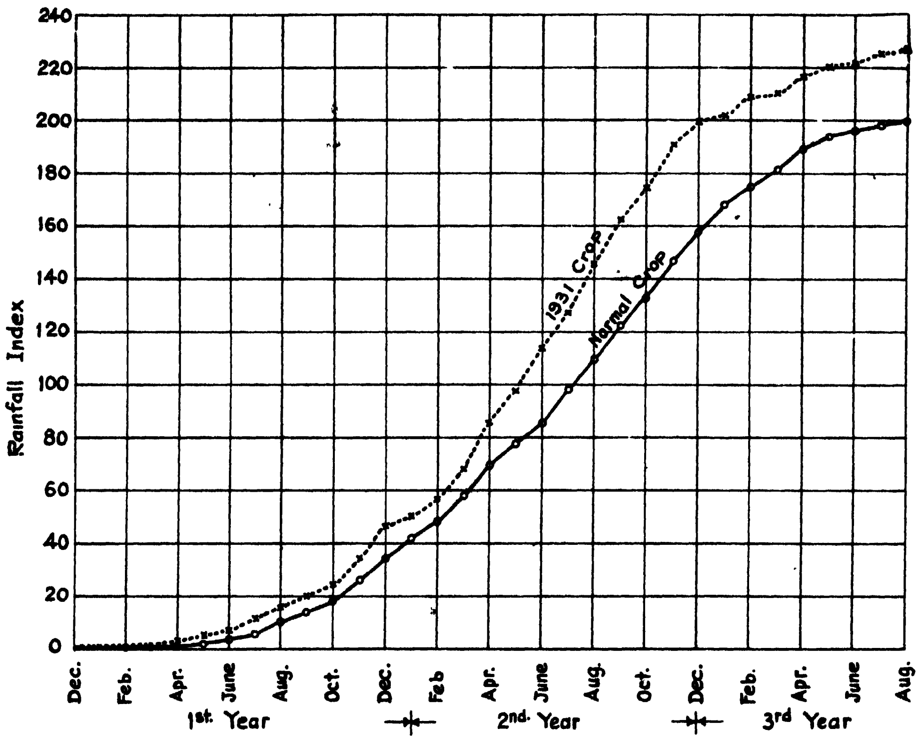


Fig. 1

TEMPERATURE

Following the method suggested by the Experiment Station, we measure effective temperature as degrees Fahrenheit above 72 degrees of mean maximum temperature. The base line of 72 degrees is admittedly arbitrary but it appears to agree well with our observations and it may later be modified if future observations seem to warrant a change. Using this base, we calculate what may be called "effective acre degrees" of heat, which is simply the area under cultivation multiplied by the effective temperature for the month. In this case we assume one degree of heat to be as effective on young cane as on old cane, though here again

refinements might be possible did they not introduce such complications into the calculations. As above, the monthly figures of "effective acre degrees" of heat are accumulated from the start to harvest of a crop. As an example, if the area harvested in January is 300 acres and the mean maximum temperature for that month is 78 degrees, 300×(78—72) or 1800 will be the "effective acre degrees" for the month.

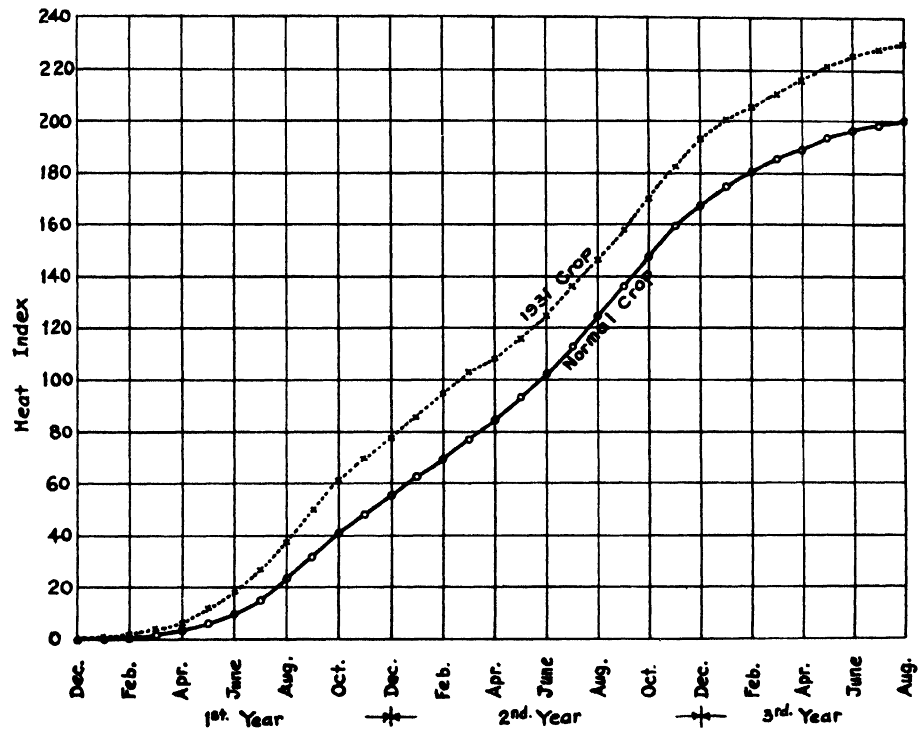


Fig. 2

Sunlight

As we have no figures for sunlight at Waiakea, we have used the data on record at the Federal Building in Hilo. These data are reported as so many clear, partly cloudy and cloudy days for each month. Assuming a clear day at Hilo to have about 40 per cent sunlight under average Waiakea conditions, a partly cloudy day 20 per cent, and a cloudy day 10 per cent, we can obtain an index figure for sunlight in the different months. If this index figure is multiplied by the possible hours of sunlight for an average day in any particular month, we obtain an approximation of the actual hours of sunlight per day at Waiakea.

Similarly as in the cases of rainfall and temperature, explained above, the area under cultivation multiplied by the sunlight index will give "acre sunlight hours," here again the assumption being that sunlight is as effective on young cane as on old cane. This assumption might also be criticized in that the effect of sunlight might be considered proportional to the total leaf area exposed to its effects, but here again we must plead simplicity as against strict accuracy.

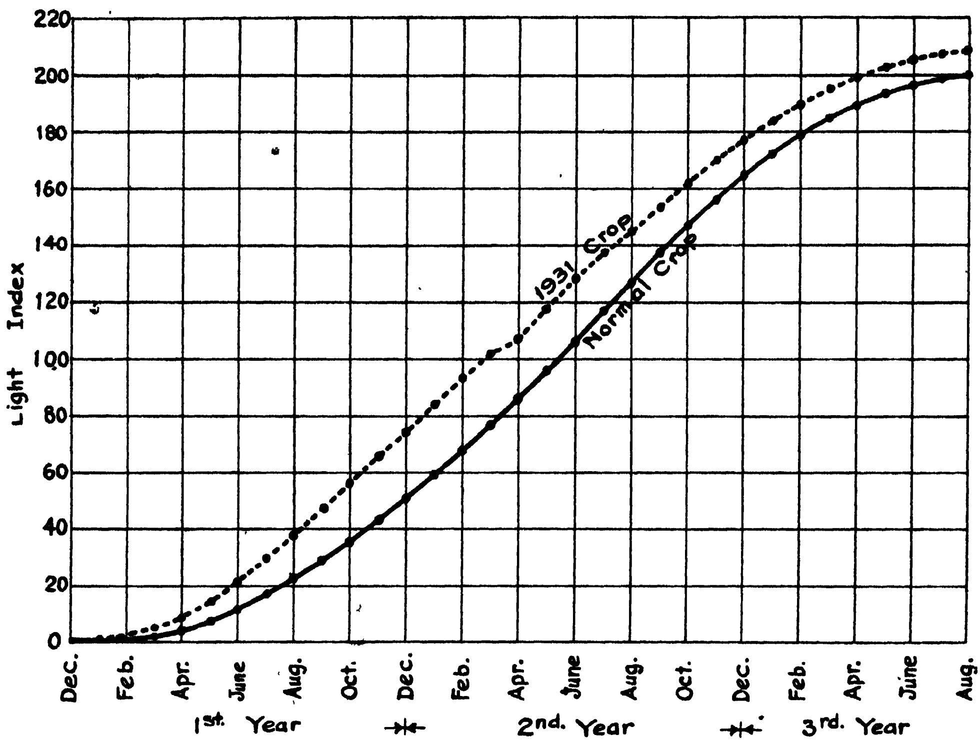


Fig. 3

Wind

At Waiakea we seldom have heavy winds. For this reason, we have not attempted to introduce this factor into the picture, assuming that the effect of wind will be uniform from month to month and from crop to crop. Any plantation where the wind varies greatly in velocity could not afford to make this assumption, however, and some inverse ratio of wind velocity would have to be used to complete the charts. Possibly a negative factor such as "acre miles" of wind travel might be developed.

Combined Effect of Weather

So far, we have considered rainfall, temperature and sunlight as separate factors. Until more is known about the relative values and importance of these factors, possibly it might be better to attempt to evaluate each factor separately as to its effect on yield. However, we have made one more assumption: that each of the three factors is of equal importance to crop production, and on this basis have attempted to combine all three factors into one unit which we may call our "Weather Index." It is as yet too early to judge whether this one figure will give us all the information that the three separate figures will, but we feel that in any case it is important to carry all four curves, as the interrelation of the different curves may lead to interesting developments on the prediction of juice quality as well as cane yield.

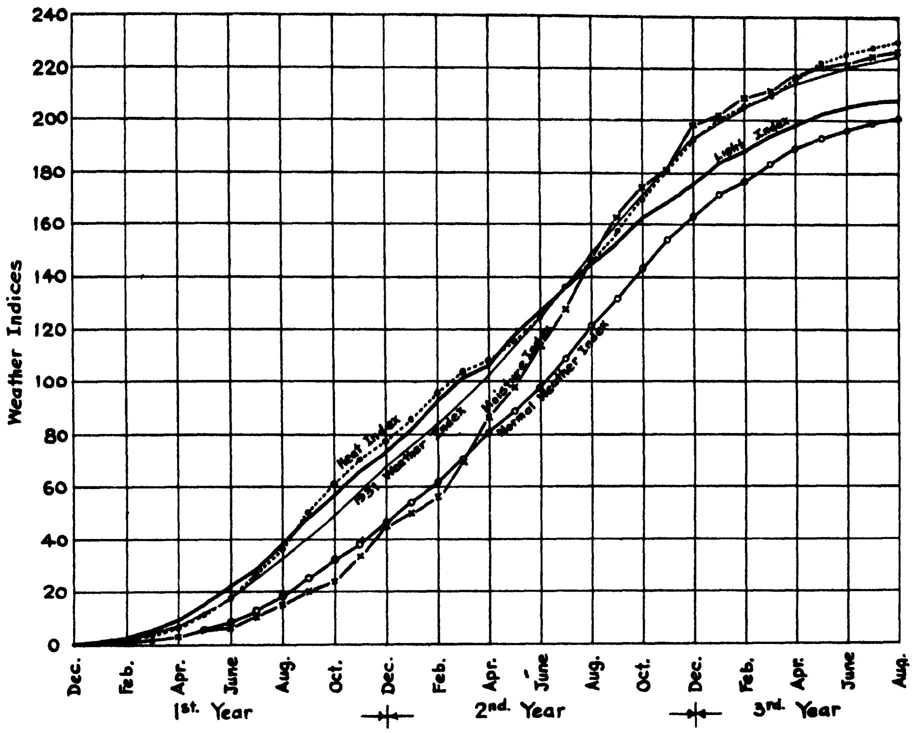


Fig. 4

Charts

Before plotting any of the figures, the derivation of which is outlined above, we have reduced all of them to a "per acre" basis. That is, "effective acre inches," "effective acre degrees" and "acre sunlight hours" obtained for each month are divided by the total crop area to obtain the corresponding figure "per acre." The figures so obtained are comparable from crop to crop and we term them, respectively, the "Moisture Index," "Heat Index" and "Light Index." As indicated just above, the combination of the three is termed the "Weather Index," and in this combination we assume that on the final yield of cane each component exerts an equal influence. In other words, we may say that each factor is responsible for fully one-third of the total weather influence and the "Weather Index" is the arithmetical average of the three subindices.

If the monthly indices outlined above are plotted on a chart against time, we have a series of curves which indicate the monthly variations in rainfall, temperature and sunlight, and the monthly weather curve. If weather exerts the powerful influence that we feel it does, this weather curve should closely follow the curve of growth measurements for any crop, and a good check on the accuracy of the assumptions could be provided by such a comparison.

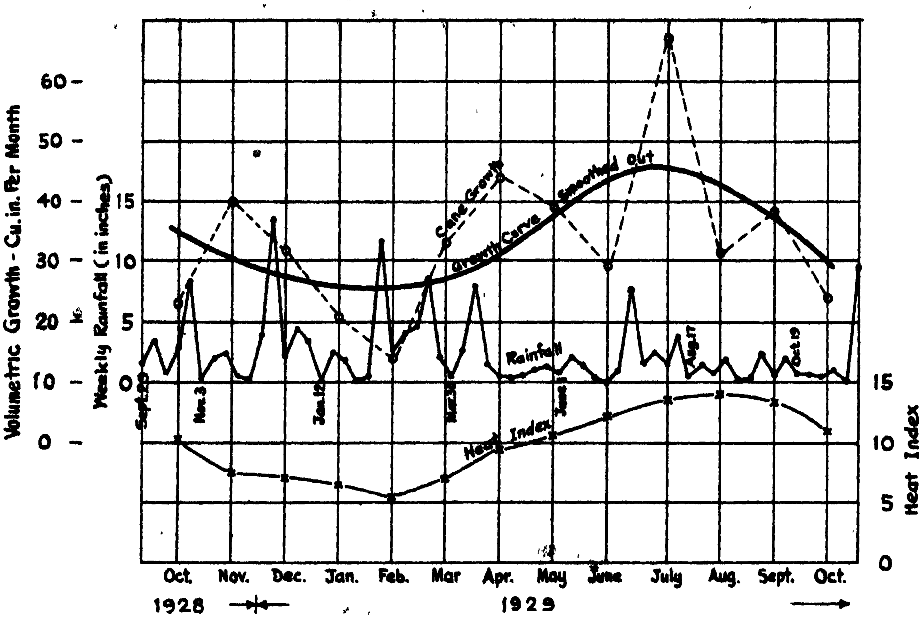


Fig. 6

If the monthly index figures are accumulated and plotted on a chart against time, together with the curve of normal or average weather conditions made up as outlined in the early part of this paper, we have a comparison of current with normal weather conditions which is fairly accurate and which will tell at a glance whether any crop has had normal, subnormal or better than normal conditions from its start up to the time under consideration.

Weather charts accurately compiled should prove to be of great assistance to a manager in following his crop progress, in supplementing his visual observations as to the productivity of any one crop, and as a check on crop estimates, particularly on the first one made usually before harvesting is actually started.

Fig. 5 shows the great variations in the different weather factors we have experienced in the last few years.

Quality of Land

In this study at Waiakea, we have introduced a correction for the quality or fertility of the land area harvested from month to month. This seemed necessary to us due to the wide variation in the productivity of different types of land on this plantation. While this factor may vary as much as from 70 per cent of average in some months to 120 per cent of average in others, we find the maximum departure from normal for any crop to be not more than 1.5 per cent for the whole crop area. For this reason, while we feel that we must continue to use a corrective factor for land fertility at Waiakea, we do not believe this to be a significant figure, particularly for plantations whose area is more uniform. The determination of this factor requires more time than all the rest of the calculations put together, and it adds so many complications to the work as to render it more of a liability than an asset.

Slope of Land

A recent article by Cornelison, appearing in *The Hawaiian Planters' Record* for the fourth quarter of 1932, indicates that a corrective factor for slope of land may be necessary to arrive at correct sunlight index figures. This factor might also be of importance with respect to prevailing winds and the rapidity of rainfall run-off in times of heavy precipitation.

Other Weather Factors

Besides rainfall, maximum temperature, and sunlight, which we have used in our calculations here, we have mentioned wind as a possible factor in some localities. There is also the factor of minimum temperature, which we have not used further than to record and chart it. This item should not be entirely overlooked, as there are indications pointing to a possible correlation between minimum temperature and cane ratio. The range of temperature is another factor which may prove significant on further study. The concentration of carbon dioxide in the atmosphere is still another factor which may be studied at some later time, having already had a certain amount of attention in Germany in connection with the forced production of certain crops under glass.

Conclusion

The small beginning that we have made in measuring crop progress in terms of weather factors makes us realize that in future it may be possible not only to express our yields "per acre," and "per acre per month," but also in terms of units of growth value, "effective acre inches of rainfall," "thousands of day-degrees," "acre sunlight hours" or as pounds of cane per "Weather Unit." Then only will it be possible to effectively compare one year's yield with another, one soil type with another, and one plantation with another.

Before closing, we wish to sound a warning to all plantations in the Territory and to those along the Hilo coast in particular. For the past five years we have had bumper crops. Records have been broken and broken again. We have all been taking a great deal of credit for improved methods of cultivation, better fertilizer practices and a general improvement in efficiency. This five-year period has been characterized by an abundance of labor. That is one factor. But still more important than the labor situation, we have had weather far above the average for each and every one of these five years. We cannot and must not delude ourselves into thinking and believing that the weather has changed permanently. There is no "New Era" in weather conditions any more than there was in economic conditions in 1928. For every year above normal there must be a year below normal, and the longer the good weather lasts the longer or the more severe will be the period of bad weather to follow. Just as surely as booms are followed by years of depression, just as surely are we heading for a "weather depression," and when that period of bad weather comes, and our yields fall back to more normal figures, it will be of some advantage to have our alibi prepared.

ACKNOWLEDGMENT

At this point we wish to express our appreciation of the work done by U. K. Das, of the Experiment Station, H. S. P. A., which really aroused our interest and started us on this investigation. Mr. Das has also outlined this article, assisted in its preparation, and prepared all the charts shown herewith for publication. Royden Bryan, of the Experiment Station, has helped us on the formulation of reasonable assumptions, while H. P. Agee has been of great assistance, giving his advice on many occasions and maintaining his interest in the progress of the work at all times.

Some Physical Constants for Certain Hawaiian Sugar Cane Soils

By H. A. WADSWORTH

Recent studies of some of the physical constants of representative samples of soil from the islands of Hawaii and Maui suggest interesting correlations which may aid in an understanding of some aspects of current cane-growing problems. For instance, it seems evident that plantations which are notable for low quality ratios and higher sugar yields are located on soils of high volume weight, or, speaking less accurately, on soils of high density. Another correlation of suggestive interest is that existing between the tendency of a soil to fix phosphate and the ratio of silica to the oxides of iron and aluminum in the colloidal separate of the soil.

It should be immediately recognized that no causal relationship is necessitated by such correlations. For example, cane of high quality may usually grow on soils of high volume weight, but it is not necessarily true that the good quality is due to the heavy soil. It would seem more logical to assume that the same characteristics of rainfall and temperature, which conspire to produce high sugar yields, are also factors in the production of soils of high volume weight. Nevertheless, the correlations are highly suggestive.

The soils used were collected during the summer of 1932 on the two eastern islands. Although listed by plantations and field numbers, it must not be assumed that the characteristics noted are typical of the entire plantation or even of the field noted. The samples were chosen to indicate typical regional conditions of soil formation and supposedly represent the entire range of weathering conditions and original materials. Eighteen samples were secured; seventeen of these were carried through the complete sequence of tests. The source of the soils used is given in Table I.

TABLE I

ORIGIN OF SOILS USED FOR MEASUREMENT OF PHYSICAL CONSTANTS

Soil Number	Island	Plantation	Field Number	Remarks
2	Maui	Maui Agric. Co.	Field 1	H. S. P. A. Nursery
3	Hawaii	Honokaa Sugar Co.	Homestead Field 1	P_2O_5 deficient
4	Hawaii	Hilo Sugar Co.		H. S. P. A. Station
5	Hawaii	Union Mill Co.	Kynnersleys 97	Experimental Area
6	Maui	Maui Agric. Co.	Field 84	High producing
7	Hawaii	Niulii M. & P. Co.	Field 27	
8	Hawaii	Laupahoehoe Sugar Co.	Field 5E	P_2O_5 fixation
9	Hawaii	Olaa Sugar Co.		P_2O_5 fixation
10	Hawaii	Olaa Sugar Co.		P_2O_5 fixation. Rich in organic matter.
11	Maui	Wailuku Sugar Co.	Field 68	No fertilizer except N.
12	Hawaii	Pepeekeo Sugar Co.	Field 6	High producing
13	Maui	H. C. & S. Co.	Field 3	High yield after fallow
14	Hawaii	Honokaa Sugar Co.	Homestead Field 1	Hollow
15	Maui	Maui Agric. Co.	Field 85	Growth failure
16	Hawaii	Pepeekeo Sugar Co.	Mud flow	
17	Hawaii	Hamakua Mill Co.	Field 27	P_2O_5 fixation
18	Hawaii	Hamakua Mill Co.	Field 26	H. S. P. A. composite

Since the physical constants usually used for soils may not be familiar, a brief description of what each represents is necessary. The following constants were measured:

(1) *Volume Weight:* This is the weight of a unit volume of soil, when the weight is expressed on the basis of oven-dry soil. In the present study a large diameter glass tube of known volume was filled with air-dry soil. The weight of this soil *after oven drying,* divided by the known volume, gives the reported volume weight. This method is arbitrary and is not to be confused with that used in the measurement of volume weight under field conditions.

(2) *Ignition Loss:* An oven-dry soil is one which has been dried at about 110° C. for 24 hours. There is no assurance that a significant further loss of weight might not occur if the temperature were increased. This additional loss might consist of organic matter burned away at the high temperature, water of crystallization and water so tightly held to the grain surfaces that only a high temperature could free it. The sum of these losses is called loss on ignition. The temperature used was 600° C. for 45 minutes. The ignition loss is expressed as the percentage of the oven-dry weight.

(3) *Moisture Equivalent:* The procedure used in the determination of this constant is too well known to demand repetition. It is our best single value constant and is expressed as a moisture percentage.

(4) *Loss of Moisture Equivalent on Oven Drying:* Ordinarily, the moisture equivalent procedure is applied only to air-dry soils. The moisture equivalents of soils which have been oven dried are usually less than for air-dried soils. In the present study the moisture equivalent of the oven-dry soil was subtracted from that of the air-dry soil and the difference divided

by the air-dry moisture equivalent. This result is expressed as a percentage.

(5) *Wilting Percentage:* Although not a technical definition, the wilting percentage may be considered as the lowest percentage of moisture in a soil which will permit normal plant growth.

(6) *Phosphate Fixation:* The H. S. P. A. fixation kit was used to measure this constant. The procedure was slightly modified, however, so that comparable weight of soils might be exposed to the phosphate solution. Two grams of soil, on the oven-dry basis, were used in all cases. The values given are from the color comparison tubes provided with the kit.

(7) *Chemical Composition of the Colloidal Fraction:* It may perhaps be assumed that the active part of a soil is the finely divided material or the so-called "colloidal fraction." This material was separated from each of the soils and analyzed chemically. The best single value obtainable from such analyses seems to be the ratio of the oxide of silica to the oxides of iron and aluminum. This is reported as a molar ratio and listed as $\frac{\text{"}SiO_2\text{"}}{R_2O_3}$.

Since the organic matter would escape detection in the analysis suggested above, this constituent was determined independently. The results are listed under the head "Organic" and are expressed as percentages by weight.

The results of the determinations are given in Table II. Several generalities may be drawn at once from the data in Table II. The Maui soils, marked with an asterisk for convenience, are consistently high in volume weights and SiO_2/R_2O_3 ratios and consistently low in the other characteristics, including the organic matter in the colloidal fraction.

TABLE II

PHYSICAL CONSTANTS OF SELECTED SOILS FROM HAWAII AND MAUI

Soil No.	Vol. Weight	Loss on Ignition	M. E.	Per Cent Loss of M. E. on Oven Drying	Wilting Percentage	P_2O_5 Fixation	Composition of Colloidal Fraction $\frac{SiO_2}{R_2O_3}$	Composition of Colloidal Fraction Organic
2*	0.96	15.2	33.1	3.9	25.9	0	1.44	1.1
3	0.52	35.9	68.0	44.5	48.2	80	0.50	10.7
4	0.59	26.0	57.4	24.5	51.3	80	0.75	7.0
5	0.87	17.0	36.8	12.5	29.0	40	0.90	3.3
6*	1.06	11.9	25.4	0.0	17.3	0	1.44	0.7
7	0.94	13.7	36.7	10.0	26.8	40	0.99	..
8	0.67	26.2	57.5	20.4	40.0	60	0.49	5.4
9	0.25	34.6	103.2	59.2	51.5	70	0.53	8.4
10	0.23	41.0	66.3	42.0	...	90	0.42	..
11*	0.98	12.4	30.8	4.2	22.7	0	1.86	1.4
12	0.57	28.5	58.0	28.6	37.5	50	0.41	8.8
13*	1.10	8.2	23.5	0.0	17.1	0	1.58	1.0
14	0.55	35.0	66.7	43.1	49.7	80	0.63	6.9
15*	1.05	10.9	27.5	8.2	18.8	0	1.55	0.9
16	0.14	22.0	297.0	89.5	173.1	90	0.38	4.0
17	0.38	34.2	105.0	71.0	73.8	80	0.42	6.8
18	0.55	30.0	56.0	51.3	46.7	80	0.59	5.5

The Kohala soils (5 and 7) seem more similar to the Maui soils than to those from Hamakua and Hilo.

As indicated in Table I, Soils 6 and 15 are from Maui Agricultural Company and were taken within a short distance of each other. Although Soil 15 is from a reputed "growth failure" area, the similarity of the soil constants for this soil and Soil 6, which is high producing, would indicate that the failure in Pulehu Field 85 was due to a chemical or biological condition and not to any physical characteristic.

A more comprehensive view of the interrelations indicated above is possible in the graphs.

Fig. 1 shows the relation between the volume weight and ignition loss. The correlation between the values is rather surprising as is the segregation of the soils in three general classes, which coincide with geographical position. Soil 16 is abnormal in most of its characteristics and widely escapes the correlation suggested in Fig. 1.

The same geographical segregation is noted in Fig. 2. Although the correlation between the factors considered in Fig. 2 is not lineal, as in Fig. 1, it seems none the less real. This condition may be brought about by the attempt to force the results from the fixation kit into quantitative aspects.

The non-lineal relation noted in Fig. 2 is again noted when the SiO_2/R_2O_3 ratio of the colloidal fraction is compared with the loss on ignition. Here, however, another possibility suggests itself. If the silica is associated with low ignition losses and the iron and alumina with high ignition losses, the hyperbolic nature of Fig. 3 would necessarily result in view of the SiO_2/R_2O_3 ratios used for the ordinates. Moreover, the relative richness of the Hamakua and Hilo soils in organic matter would tend to result in an increased loss on ignition.

The correlation coefficient between P_2O_5 fixation and the SiO_2/R_2O_3 ratios (Fig. 4) is —0.92, which is surprisingly high in view of the vagueness of the quantitative aspects of the P_2O_5 procedure. Here, again, one might expect a hyperbolic form of curve, as in Fig. 3.

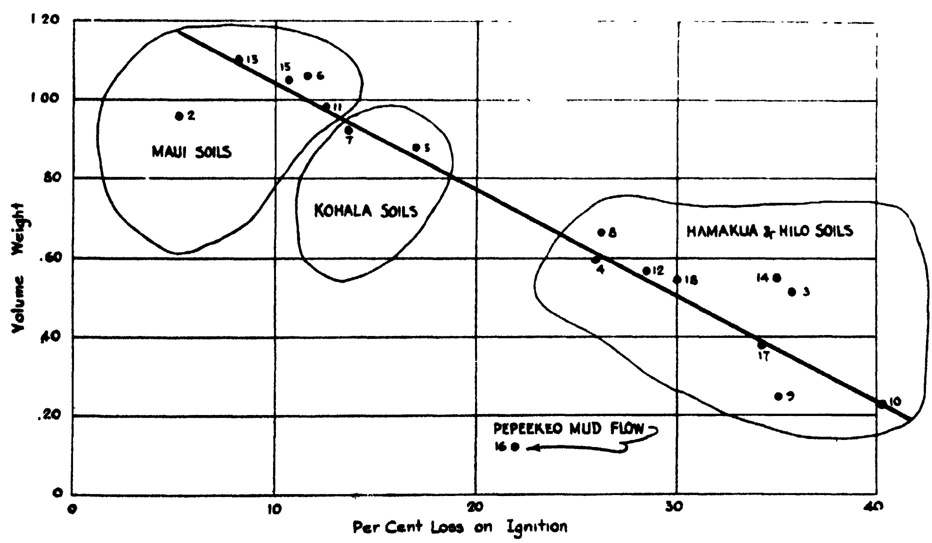


Fig. 1

The losses upon ignition for the seventeen soils as related to the volume weights.

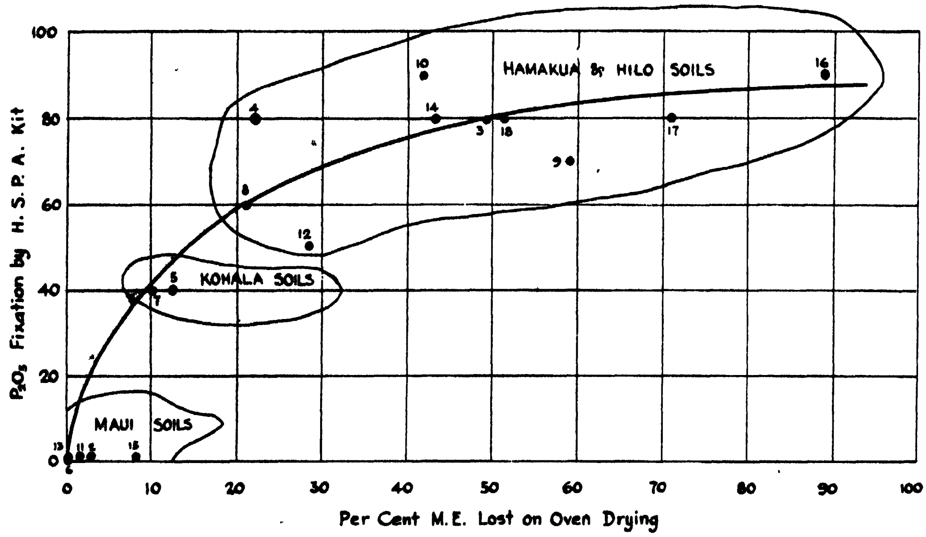


Fig. 2

The decreases in the moisture equivalents upon oven drying as related to phosphate fixation, as measured by the Experiment Station, H. S. P. A. fixation kit.

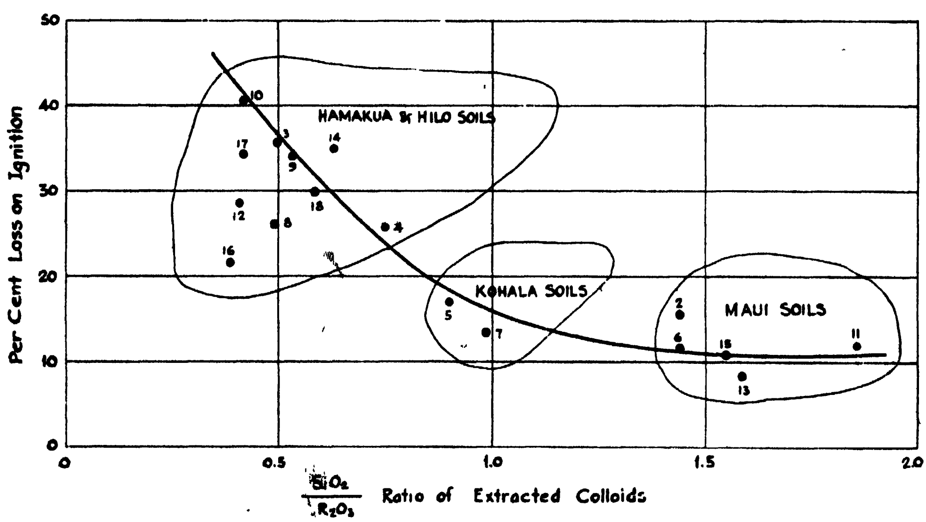


Fig. 3

The proportions of silica to iron and aluminum in the ~~extracted~~ colloid as related to ignition losses.

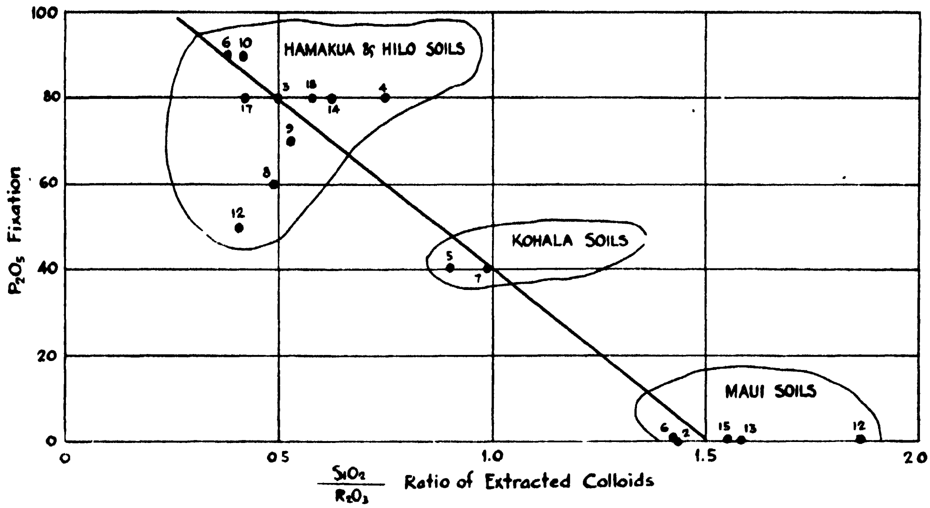


Fig. 4

The ratios of silica to iron and aluminum in the extracted colloids as compared to the phosphate fixation, as measured by the Experimental Station, H. S. P. A., fixation kit.

Discussion

Several interesting suggestions are offered in the results presented above. In perfect accord with the argument of some recent workers in the study of soil origin, we find soils rich in colloidal iron and alumina and lean in silica on the windward or rainy sides of the two islands reported, while in drier regions the silica seems the more permanent, iron and alumina being lost by leaching. The reason for this differential leaching is not perfectly understood; the arguments advanced to support the opinions offered need not concern us. Be the cause what it may, most modern workers are convinced that continuous leaching results in a soil that is lean in SiO_2 and relatively rich in the oxide of iron and aluminum. Again in accord with popular opinion, the soils from the regions of high rainfall carry more organic matter than others, partly perhaps because the organic matter is more rapidly formed in such locations, but also because it is more slowly decomposed.

The data also suggest that other modifications of the soil take place during the leaching process along the rainy coasts of Hawaii. These soils absorb and hold large amounts of water either because of the fine grain sizes involved or because of chemical hydration. Two soils from Hamakua Mill Company (18 and 17) held 52 per cent and 86 per cent of their oven-dry weight as moisture when in a so-called "air-dry" condition. This absorption or adsorption of water tends to bring about a low volume weight since only the oven-dry material is used in the computation of this characteristic. Fig. 1 seems to support the conclusion that volume weight decreases as rainfall increases. A study of the value of this correlation with modern rainfall records does not seem of great value.

As has been indicated, large amounts of water are tightly held by soils of the Hamakua region. Consequently, the moisture equivalents of these soils are high.

When oven dried, however, a large part of this water is driven off; nor can it be immediately replaced by again saturating the soil as is done in the moisture equivalent procedure. This irreversible process is well illustrated by the sample from the mud flow area above Pepeekeo (16). In its original air-dry condition this soil had a moisture equivalent of 297 per cent. When oven dried, a process which resulted in great loss of volume, a moisture equivalent of 31.4 per cent was observed, or a loss of 89.5 per cent.

The ignition loss, too, seems closely related to the conditions of weathering through which the soil was formed. Although the Hamakua soils are richer in organic matter than those from central Maui, it seems illogical to assume that the great differences in ignition loss are due to this factor. A more logical explanation seems to lie in the belief that large amounts of water are combined with the Hamakua soils and are so tightly held by some physical or chemical bond that a temperature of 110° C. fails to liberate it.

The phosphate-fixing aspects of the soils are not as readily visualized as the other characteristics. Regardless of the causal relation and assuming that the phosphate fixation kit may with proper precaution be used as a rough quantitative measure of the tendency for a soil to fix phosphate, we see a steady and continuous increase in this tendency as the intensity of the weathering increases. Since there seems to be no such continuous increase in the percentage of colloidal matter in the soil as measured either by the hydrometer or by the heat of wetting, one naturally turns to the nature of the colloidal matter involved in an effort to interpret the relation which seems to exist. From the many analyses of similar material reported in the literature, it is evident that about 90 per cent of the colloid is a mixture of oxides or compounds of silica, iron and aluminum together with the material lost on ignition, which includes organic matter. Most writers have used the ratio secured by dividing the number of moles of SiO_2 by the sum of the moles of Al_2O_3 and Fe_2O_3 to express the chemical and physical activity of the colloid. In the present case, the correlation coefficient of —0.92 between this ratio and our measure of phosphate fixation seems highly significant. Regardless of the chemistry involved, we have some statistical evidence, questionable as it may be, that an abundance of colloidal iron and aluminum would tend to fix phosphate, while any silica present not only failed to fix this material but seems to actually depress the fixing ability of the iron and aluminum present.

This possibility was explored by assuming that each mole of SiO_2, Al_2O_3 and Fe_2O_3 had the capacity of fixing a certain weight of soluble phosphate, and from the seventeen equations available computing the values indicated. The most plausible values secured by the methods of normal equations were:

Al_2O_3=2.07 units of fixation per cent.
Fe_2O_3=2.18 units of fixation per cent.
SiO_2=—2.56 units of fixation per cent.

When the computed fixations of the soils upon the basis of their chemical analysis and the constants given above are compared with the observed values, a correlation coefficient of +0.82 is secured.

Although such a procedure may be highly questionable, it might be interpreted

to give some additional evidence that silica in the soil colloid may offset the fixing powers of aluminum and iron which may be present. Recent efforts by some plantations to reduce the phosphate-fixing character of their soils by adding soluble silicates should be noted in this connection.

Summary

(1) The physical properties of seventeen typical soils from Maui and Hawaii are given as a result of recent work at the University of Hawaii.

(2) The nature of the soils as measured by the physical properties mentioned seems to depend upon the conditions of weathering under which the soils were formed. Soils from windward Hawaii are characterized by low volume weights, high ignition losses and high phosphate-fixing characteristics. Soils from Maui exhibit high volume weights, low ignition losses, and little or no phosphate fixing capacity. The interrelations of these characters are illustrated by graphs.

(3) The results from a "growth failure" area at Maui Agricultural Company as compared with a neighboring area, indicate that the failure is not traceable to a physical characteristic of the soil.

(4) Some evidence is offered that phosphate fixation in the local soils is due to an abundance of iron and aluminum in the colloidal separate of the soil. Moreover, the presence of silica in the colloidal separate seems to act as if it had the capacity of minimizing the fixative characteristic of the iron and aluminum with which it is associated.

Investigation of the Effect on the Strength of Lime Mortar by the Addition of Molasses

By J. A. Swezey

This investigation was made to determine what effect the addition of molasses to lime mortar had on the strength of the mortar.

Drs. Gerald J. Cox and John Metschl, of the Mellon Institute of Industrial Research (*Rock Products*—May, 1932, and *Sugar Bulletin*—May, 1932), reported early in 1932 that when sugar equivalent to 6 per cent by weight of quicklime was added to lime mortar, the tensile strength of the mortar was increased by 60 per cent (approximately) at an age of 6 months.

Cox and Metschl in their report gave very little information as to their procedure of testing other than to mention briefly the proportions of lime, sand, and water used to make the mortar, and that they used A. S. T. M. standard tensile briquette molds.

The procedures employed in the present investigation followed as nearly as possible the specifications of the A. S. T. M. Inasmuch as this society has not yet adopted a standard method of testing the strength of lime mortar, the methods

described below are to some extent original and were designed to give the most practical comparative tests possible.

The present investigation was conducted in the engineering laboratory of the University of Hawaii by the writer, assisted by A. H. Cornelison.

Materials Used

Quicklime—Roche Harbor Brand—manufactured at Roche Harbor, Wis. (Supplied by courtesy of Lewers & Cooke, Ltd., Honolulu.)
Sand—20- to 30-mesh, standard Ottawa sand.
Water—Tap water from Honolulu water supply system.
Sugar—Commercial refined sugar (supplied by sugar technology department of the Experiment Station, H. S. P. A.)
Molasses—Straight commercial run of molasses (supplied by Oahu Sugar Company) having the following analysis:

Gravity solids	95.35%
Sucrose	33.40%
Gravity purity	35.03%
Glucose	16.74%
Ash potash	13.33%

Brick—Red *pressed* brick, used to make up certain test samples. Dimensions: 8¾″ x 2 7/16″ x 4 3/16″.

Apparatus

Molds—Standard A. S. T. M. briquette, cube, and cylinder molds.
Machines—Riehlé Briquette Testing Machine.
Olsen 20,000 lb., Universal Testing Machine. Riehlé 150,000 lb., Universal Testing Machine.

Mixing and Molding

The batches of mortar were mixed as follows: The lime was slaked by adding 2¾ parts of water to 1 part of lime (by weight). The resulting paste or putty was stirred for 3 hours and then daily until used. The first group of samples was made with putty aged only 24 to 48 hours. Early tests of samples at an age of 8 weeks indicated that a longer period of aging for the putty was required. A second group of samples was therefore made of putty aged 2 weeks or more. Putty aged at least two weeks was quite free of unslaked lime grains, which in short-aged putty undoubtedly weakened the sample pieces by "exploding" during the setting of the mortar.

To the lime putty was added 3 parts, by weight, of 20-30 mesh standard Ottawa sand to 1 part of unslaked lime. The putty and sand were thoroughly mixed into a mortar, to which was added the desired amount of adulterating molasses dissolved in ¼ part of water to the 1 part of unslaked lime.

The final proportions of the mortar were then:

1 part unslaked lime
3 parts standard sand
3 parts water
"X" parts molasses

Note:—One set of samples was made of mortar containing 6 per cent of refined sugar, to compare with the results reported by Cox and Metschl.

As soon as each mortar batch was thoroughly mixed it was placed in the various molds, being pressed and tamped well to occlude air bubbles. The molds were removed immediately the mortar had attained sufficient set to maintain shape unsupported.

Some interesting observations were made as follows:

(a) Molasses and mortar, mixed in equal parts, generated considerable heat. Sugar and mortar, mixed in equal parts, did not generate any noticeable heat.
(b) The molasses stained the mortar to a brown color, the greater the amount of molasses in the mortar the darker the color. Apparently in the more slushy mixes the molasses floated to the top of the samples during the "initial set" period, thus staining the top surface more than the interior.
(c) Unless the putty was thoroughly stirred and aged, plain mortar shrank unevenly, causing checks and cracks to appear in the sample pieces, thus weakening them. The addition of molasses tended to relieve this condition, the molasses apparently having a binding effect.
(d) Mortars containing 6 per cent or more of sugar or molasses were quite fluid and slow to set, the degree of fluidity and the time of set increasing with increase in the proportion of the sucrose present in the mortar.

Description of Sample Pieces

Briquettes. Briquettes, formed in the standard A. S. T. M. molds, were originally to be subjected to the tension test for which this type of sample is especially designed, but as will be explained under "Description of Tests," they were finally tested under compression.

Cubes. With A. S. T. M. molds, 2-inch cubes were made. These cubes were tested in compression.

Cylinders. With A. S. T. M. molds, 2-inch diameter x 4-inch long cylinders were made for compression tests. Cylinders of 1:3 lime mortar only were made, for a comparison with the other types of samples.

Brick Masonry. To make practical comparative tests of the strength of the various mortars, red pressed-brick were set up with the mortar in the joints.

The samples thus made each consisted of two bricks laid together edgewise with a mortar joint approximately ¼″ to ⅜″ thick.

Description of Tests

Briquettes. At an age of 6 months an attempt was made to test the briquettes under a tension load; however, in the tension testing machine the briquettes did

not fail across the smallest cross-sectional area (1 sq. inch), but the failure occurred in either one of two planes of shear, indicated in Fig. 1A.

Since it was evident that the briquettes would not give satisfactory comparative tensile strength tests, they were subjected to compression, applied perpendicularly to the flat surfaces. (See Fig. 1B.)

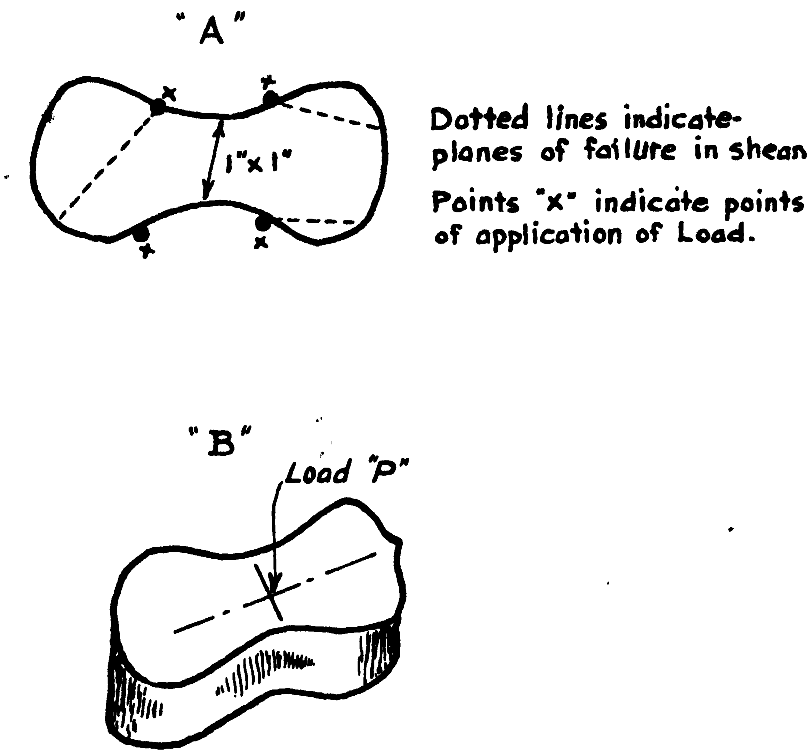


Fig. 1

The area to which the load "P" was applied was obtained by laying each briquette on a sheet of paper and drawing around the edge with a sharp pencil. The outline thus drawn was measured with a planimeter to give the area in square inches.

The compression test of the briquettes proved very satisfactory. The compression load was increased to a point of complete, or ultimate, failure of the briquettes. The point of failure was easily detected by the customary "drop of the beam" of the testing machine's scale.

Ultimate failure consisted of a sudden, complete disintegration of the briquette under test. The load recorded by the machine at this point of failure was divided by the area of the top of the briquette to give the unit compressive strength in pounds per square inch.

Seven to ten briquettes constituted a test, and the average unit compressive strengths of the various batches of mortar are reported in Table I. The data are plotted as curves in Fig. 2 (A). Several batches were tested at an age of nine months, as shown in the table and curves.

It is seen that up to 6 per cent adulteration of the lime mortar with molasses produced a marked increase in the strength of the mortar. Adulterations of over

6 per cent of molasses produced strengths slightly less than for 6 per cent, but still much greater than that of unadulterated mortar.

The curve for per cent increase in strength follows closely the shape of the strength curve.

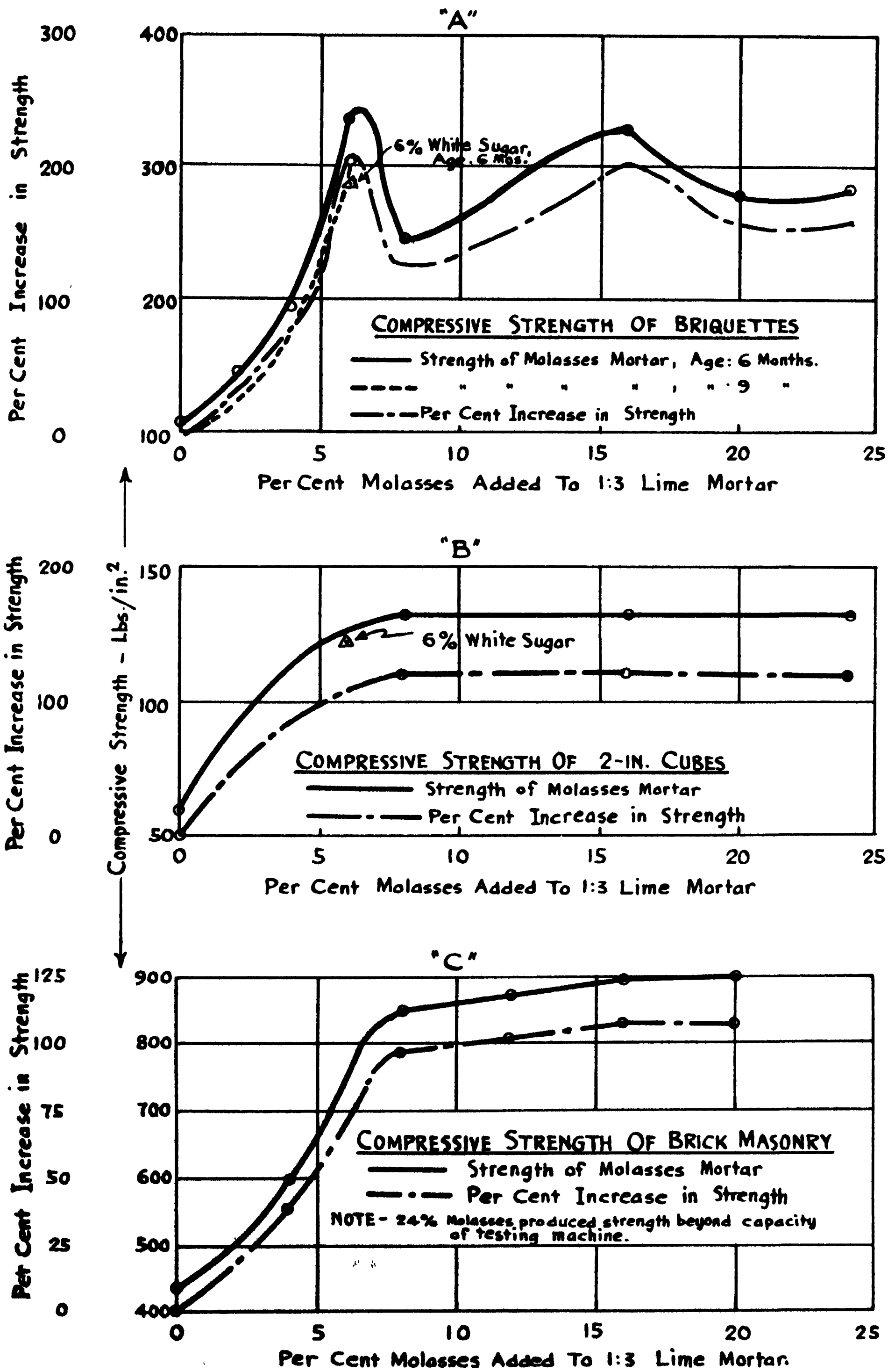


Fig. 2

At 9 months of age the strength was slightly less than at 6 months, although the difference was insignificant, considering that lime mortar requires a long period of time for attaining complete "set."

Six per cent white sugar produced almost as great an increase in strength as 6 per cent of molasses.

Cubes. At an age of 6 months the 2-inch cubes were tested in compression. As with the briquettes the point of complete failure was readily detectable by the "drop of the beam."

The data on strengths appear in Table II and Fig. 2 (B).

The strengths of the cubes are lower than for the briquettes, but again a maximum strength was produced by 6 per cent adulteration with molasses, with no further increase in strength produced by still greater adulteration.

Brick Masonry. These samples were also tested in compression. The point of failure was difficult to detect as no drop of the beam was observable up to the loading capacity of the 20,000-pound Olsen machine.

In the Riehlé 150,000-pound machine, a sample was tested to 40,000 pounds, at which load the bricks failed.

However, the mortar joint was observed, as the load was gradually increased, to swell, followed by peeling off of the harder outside skin of mortar, and finally forcible throwing out from the surface of the joint of sand grains and lime particles. This latter phenomenon was considered to indicate failure, by crushing, of the interior of the mass of lime forming the joint.

The large ratio of area to thickness of mortar accounts for no drop of the beam at failure of the mortar. Therefore, the load was increased from "0" until sand and lime began to drop out of the joint; the load at this point was taken as the failure load and used to compute the unit strength.

In spite of the difficulty of detecting failure of these samples the data and curves (Table II and Fig. 2 [C]) show strengths parallel to the other types of samples, i.e., increase of strength with increasing adulteration up to 6 per cent, then no additional increase of strength beyond 6 per cent adulteration.

Cylinders. The 2-inch diameter x 4-inch-high cylinders of 1:3 mortar were tested in compression, to complete failure. Table III shows the strengths of 1:3 mortar briquettes, cubes, brick masonry, and cylinders compared with the corresponding heights, or thicknesses of mortar also tabulated. The data are plotted in Fig. 3—strength vs. thickness. The curve presents a guide to the strengths that may be expected from various thicknesses of mortar, and is exhibited to explain why, with any one of the given per cents of adulteration, the strengths vary so greatly between types of samples. It is natural to expect that the thinner the mortar the greater the unit strength.

Summary and Conclusions

In this investigation lime mortar was subjected to compression tests unadulterated and adulterated with varying percentages of molasses.

Compression tests were employed rather than tension tests, because compres-

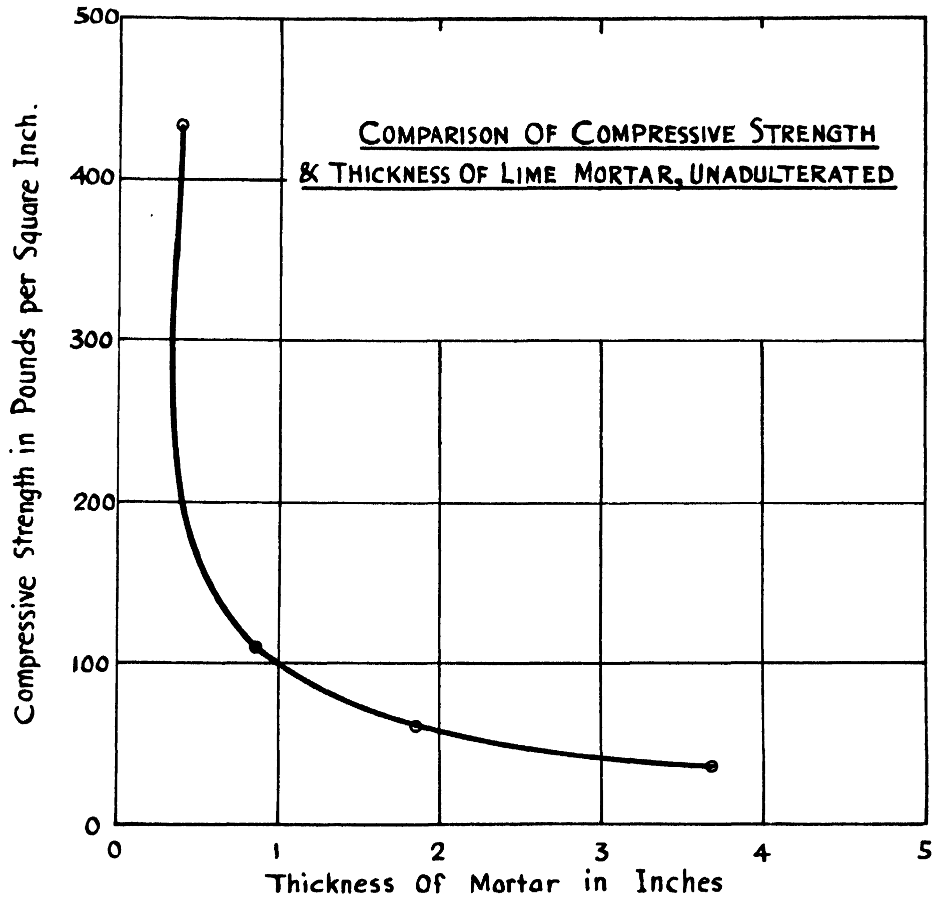


Fig. 3

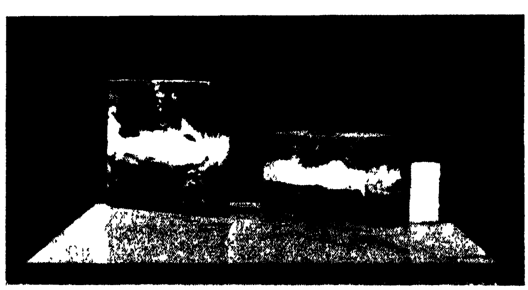


Fig. 4

sion tests were considered of more practical value, lime mortar seldom, if ever, being used in situations where it would be under tensile stresses.

From the results of these tests as shown in the tables of data and the curves, the following conclusions can be made:

1. That the addition of 6 per cent of sugar will increase the *compressive* strength of lime mortar by 165 per cent. This is a far greater increase in

strength than that obtained by Cox and Metschl (60 per cent in tension), but it must be borne in mind that the compressive strength of cements, concrete, and mortars is greater than the *tensile* strength; hence any increase in strength would be much greater compressively than the corresponding increase in tensile strength.

2. That as molasses is added to lime mortar from 0 to 24 per cent adulteration, the compressive strength is increased. However, the *maximum* increase in strength was produced by 6 per cent adulteration with molasses, this increase being 206 per cent. Note that increasingly larger amounts than 6 per cent of adulteration with molasses produced increases in strength over the strength of unadulterated mortar, but these increases in strength were somewhat less than that produced by 6 per cent adulteration.

3. That molasses added to lime mortar produced a better mortar than the addition of sugar. Not only was the maximum attainable increase in strength (with 6 per cent adulteration in both cases) greater for molasses than for sugar (206 per cent increase against 165 per cent), but a more perfectly setting mortar was obtained by adding molasses. A molasses-adulterated mortar set with few, if any checks or cracks. Also, with equal amounts of adulteration with molasses and sugar, a somewhat less fluid mix was produced by the molasses. The degree of checking and cracking has a very direct bearing on the obtainable strength of mortar.

4. No definite conclusion can be stated with respect to the comparison of strengths at 6 and 9 months of age (see Table I), since the mortar tested at 9 months of age was made from lime putty insufficiently cured. However, the comparison does show that ageing quite possibly will not overcome the harmful effects of short-curing of the lime putty.

5. That the greater the thickness or height of the lime mortar, the less will be its strength. However, molasses adulteration still increases the strength of mortar more than does sugar, even in samples of large thickness.

TABLE I

UNIT COMPRESSIVE STRENGTHS OF BRIQUETTES OF 1:3 STANDARD SAND-LIME MORTARS CONTAINING VARIOUS AMOUNTS OF MOLASSES

(Note—Figures in parentheses are number of samples to each test.)

Per cent (by weight) of Adulteration	Age—6 Months: Lbs./in ^{2} Compressive Strength	Age—6 Months: Difference from 0% Adulteration, Lbs./in ^{2}	Age—6 Months: Difference from 0% Adulteration, Per cent	Age—9 Months: Lbs./in ^{2} Compressive Strength	Age—9 Months: Difference from Age of 6 Months, Lbs./in ^{2}	Age—9 Months: Difference from Age of 6 Months, Per cent
0	109 (10)	0	0	99 +	—10	— 8.85
6 (sugar)	289 (10)	+180	+165	265 (10)	—24	— 8.3
2 (molasses)	146 (8)	+ 37	+ 34	129 (10)	—17	—11.6
4 "	195 (8)	+ 86	+ 79	183 (10)	—12	— 6.2
6 "	333 (8)	+224	+206	302 (9)	—31	— 9.3
8 "	246 (7)	+137	+126	....	....	......
16 "	327 (8)	+218	+200	....	....	......
20 "	276 (2)	+167	+153	....	....	......
24 "	282 (7)	+173	+159	....	....	......

(+Computed from average of differences below.)

TABLE II

UNIT COMPRESSIVE STRENGTHS OF CUBE AND BRICK SAMPLES OF 1:3 STANDARD SAND-LIME MORTARS CONTAINING VARIOUS AMOUNTS OF MOLASSES

(Note—Figures in parentheses are number of samples to each test.)

Per cent (by weight) of Adulteration	2-inch Cubes Lbs./in 2 Compressive Strength	Difference from 0% Adulteration Lbs./in 2	Per cent	Brick Masonry Lbs./in 2 Compressive Strength	Difference from 0% Adulteration Lbs./in 2	Per cent
0	60 (4)	0	0	433 (2)	0	0
6 (sugar)	146 (4)	+86	+143	....	.....	.....
4 (molasses)	......	....	.....	596 (4)	+163	+ 38
8 "	132 (4)	+72	+120	850 (4)	+417	+ 96
12 "	......	....	.....	869 (6)	+436	+101
16 "	132 (4)	+72	+120	895 (6)	+462	+107
20 "	......	....	.....	898 (5)	+465	+107
24 "	132 (4)	+72	+120	938+(6)	+505	+117

TABLE III

COMPARISON OF COMPRESSIVE STRENGTHS OF PLAIN 1:3 STANDARD SAND-LIME MORTAR BRIQUETTES, CUBES, CYLINDERS AND BRICK MASONRY, SHOWING RELATION OF THICKNESS TO STRENGTH OF MORTAR

Type of Sample	Compressive Strength (Lbs./in 2)	Height or Thickness of Mortar (inches)
Brick masonry	433	0.375
Briquettes	109	0.875
Cubes	60	1.875
Cylinders	36	3.688

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD DECEMBER 17, 1932, TO MARCH 15, 1933

Date	Per Pound	Per Ton	Remarks
Dec. 17, 1932	2.85¢	$57.00	Cubas.
" 21	2.82	56.40	Cubas.
" 22	2.80	56.00	Cubas.
" 27	2.79	55.80	Puerto Ricos, Philippines.
" 28	2.765	55.30	Puerto Ricos, Philippines, 2.75; Cubas, 2.78.
" 29	2.78	55.60	Cubas.
Jan. 3, 1933	2.77	55.40	Philippines.
" 4	2.785	55.70	Puerto Ricos, Philippines.
" 9	2.78	55.60	Philippines.
" 12	2.75	55.00	Cubas.
" 13	2.73	54.60	Puerto Ricos.
" 16	2.70	54.00	Puerto Ricos, Philippines.
" 17	2.67	53.40	Puerto Ricos.
" 26	2.68	53.60	Puerto Ricos.
" 27	2.70	54.00	Puerto Ricos, Philippines.
" 30	2.68	53.60	Philippines.
Feb. 1	2.66	53.20	Philippines, Puerto Ricos.
" 2	2.65	53.00	Philippines.
" 8	2.69	53.80	Puerto Ricos, 2.68; Puerto Ricos, Philippines, 2.70.
" 10	2.70	54.00	Philippines, Puerto Ricos.
" 15	2.72	54.40	Puerto Ricos.
" 16	2.80	56.00	Philippines.
" 23	2.825	56.59	Cubas, Philippines, 2.85; Puerto Ricos, 2.80.
" 24	2.85	57.00	Puerto Ricos, Cubas.
" 27	2.80	56.00	Cubas.
" 28	2.85	57.00	Cubas.
Mar. 3	2.86	57.20	Puerto Ricos, 2,85; Cubas, 2.86; Puerto Ricos, 2.87.
" 4	2.90	58.00	Puerto Ricos.
" 6	3.00	60.00	Cubas.
" 7	3.025	60.50	Philippines, 3.00; Puerto Ricos, 3.05.
" 8	3.00	60.00	Puerto Ricos.
" 10	2.96	59.20	Puerto Ricos.
" 15	3.00	60.00	Cubas.

THE HAWAIIAN PLANTERS' RECORD

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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

A Historical Summary of Irrigation in Hawaii:

The task of assembling accounts of irrigation development in the Hawaiian Islands, from the prehistoric practices as reported by early explorers and adventurers to such monuments to modern skill and resourcefulness as the Wailoa Ditch on Maui and the Alexander Dam on Kauai, has not been easy. Probably it is not complete. Valuable sources of material in printed form have unquestionably remained undiscovered in spite of diligent search, while many old residents, who, through long association with developments, might contribute materially to the completed whole, have escaped interview.

The accounts of those who lived through the period of most active development have been most valuable. Among these, Mrs. H. P. Baldwin, G. N. Wilcox, Wm. F. Pogue, A. C. Alexander, Judge Antonio Perry and C. A. Buchanan have been most helpful in lifting a story of costs, dates and engineering detail into a position of compelling interest. To each of these, or to their memories, the writer extends his thanks. Acknowledgment is also due to D. H. Baldwin, W. P. Alexander and Professor R. S. Kuykendall for their helpful interest during the preparation of this account. The valuable suggestions of A. C. Alexander, W. H. Taylor and Professor R. S. Kuykendall, who critically read the original manuscript, are incorporated in the present text and gratefully acknowledged.

The preparation of this manuscript does not mark the end of the writer's interest in this study. Additional information with respect to any of the early practices or reference to obscure printed accounts will be equally welcome.

(H. A. Wadsworth.)

A Historical Summary of Irrigation in Hawaii

By H. A. Wadsworth

(Associate Professor of Irrigation Practice, University of Hawaii, and Irrigation Specialist, Experiment Station, H. S. P. A.)

Introduction

Although the practice of irrigation has long been a significant factor in Hawaiian agriculture, a study of the history of its development from a prehistoric practice among the natives to its modern use in sugar production has never been comprehensively undertaken. The story of this transition is not a simple one.

Economic as well as political developments during the period between 1850, which may be taken as the beginning of sugar irrigation, and 1878, which marked the beginning of the modern period of water utilization, had a decided effect upon what might have been a continuous but rather uninteresting development. Sugar prices suffered a severe decline in 1853, probably due, in part at least, to declining interest in the California mines. An unusual drought on Maui in 1862 and the failure of two sugar brokers in 1865 still further depressed the sugar industry.

In addition to these external effects, local developments were important. The Mahele, or land division, of 1848 gave promise of private ownership of land by individuals and companies, as well as suggesting the possibility of leasing the right to divert water from lands in government ownership. Reciprocity with the United States, attained in 1875, was another powerful stimulus to sugar cane development, while annexation in 1898 added further security.

The period of greatest interest in the history of irrigation development is marked by the greatest difficulty to one who hopes to compile a continuous story of development. Early methods with taro or other crops changed little, apparently, between the times of Cook and Vancouver and the Mahele. Plantation records, agency reports and summaries by the Planters' Labor and Supply Company, and later by the Hawaiian Sugar Planters' Association, tend to clarify the development since 1883. Between 1850 and 1883 records are scattered and incomplete. *Thrum's Annual* and the *Transactions of the Royal Hawaiian Agricultural Society* provide valuable material, as do occasional accounts of progress or editorials in the newspapers of that period. The most illuminating sources, however, are the biographies and reminiscences of those who lived through these developments or who, through close association with others active in the early works, acquired a store of anecdotes which often contribute valuable sidelights or unsuspected leads to further inquiry.

The short discussion of the water laws of Hawaii is not intended to be a statement of the modern water code of the Territory with all its ramifications. Its purpose is again historical and attempts to give the barest possible outline of the original but remarkably effective code of Hawaii.

Prehistoric Agriculture and Irrigation

That irrigation had an important place in early Hawaiian life cannot be doubted. Captain Cook (6) in his account of his first landing on Kauai, in 1778, mentions taro plantations at Waimea, saying that "the greatest part of the ground was quite flat, with ditches full of water intersecting different parts, and roads that seemed artificially raised to some height." And again, "The vale ground has already been mentioned as one continuous plantation of taro and a few other things, which have all the appearance of being well attended to." Vancouver (22) also mentions the thrifty growth of taro resulting from artificial watering.

Moreover, certain ancient Hawaiian words add evidence to the assumption that irrigation was significant, if not vital, to native life. The word "wai" meant water, while "waiwai" meant goods or wealth, leaving the suggestion, at least, that an abundance of water was associated with prosperity. Furthermore, the more common word for law or regulation was "kanawai," again suggesting that early laws dealt primarily with water distribution. It is interesting to note that a literal translation of the Old Testament in early Hawaiian would list the ten water-laws of Moses in place of the familiar Ten Commandments.

It is singular, however, that such an important aspect of native life should not find expression in the voluminous folklore and legends of the people. The *Fornander Collection of Hawaiian Antiquities and Folklore* mentions irrigation as pertinent to taro production, it is true, but such reference is secondary to the details of the usual supplications to Kane, the god of water, during the growth of the taro. Apparently the folklore of the people was devoted to the exploits of their gods and heroes and not to the commonplaces of daily life. Even David Malo (10), the source for most knowledge of early Hawaiian customs, dismisses the subject of irrigation with scant notice.

A more comprehensive account of early taro culture is to be found in Campbell's (4) account of his experiences on Oahu in 1809. Campbell emphasizes the labor entailed in the production of this crop. He describes the patches as being something less than one hundred feet square and surrounded by embankments generally about six feet high, the tops of these embankments being planted to sugar cane. Water was admitted to these patches and carried from them by carefully constructed aqueducts and drains, which, according to Campbell, required great labor and ingenuity. Another point of interest in this early account is the great depth of water used in submergence, Campbell giving from twelve to eighteen inches for this figure. The importance of puddling the soil before flooding is also noted, this being done by treading it underfoot until it was close enough to contain water.

It has been suggested that new taro beds were subject to a religious ceremony before use, this ceremony consisting, among other things, of a dance upon the wet floor of the newly leveled patch. The practical benefits of this part of the performance are evident, although no verification of this statement has been possible. Campbell's observations were later substantiated by Corney (5) in 1819 and by Stewart (18) a few years later.

Early Ditches

Although these several authorities and others mention the necessity of irrigation water for taro production, none of the earlier writers mentions the method of ditch

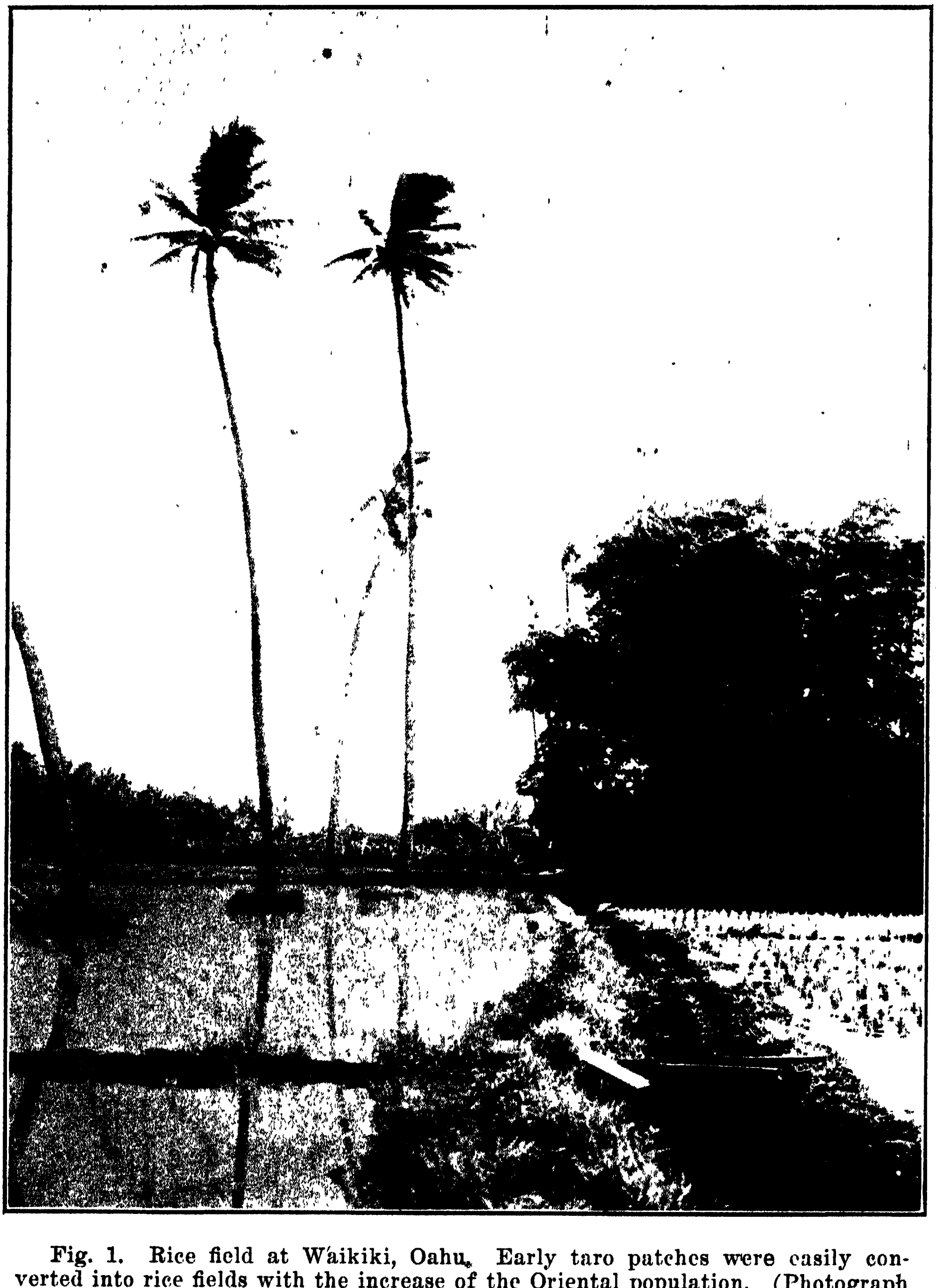

Fig. 1. Rice field at Waikiki, Oahu. Early taro patches were easily converted into rice fields with the increase of the Oriental population. (Photograph from the Bishop Museum.)

construction in any detail. Probably most of them were short and of small capacity, although some must have been more ambitious in view of Campbell's remark upon the labor involved. In any event, it seems clear that the intake structures were usually temporary, being carried away during high water and replaced when needed. As a result, few remains of veritable ancient canals exist and these only if continued maintenance work has been done. The palm-lined auwai in Fig. 4 is not ancient but may illustrate the usual appearance of early ditches. In some cases old canals have been incorporated in plantation distribution systems, but in such cases enlargements and betterments have robbed the old ditch of any evidences of peculiar construction which it may have had. Erosion and weed growth quickly obliterate a ditch if thrown out of use.

Consequently any remains of an ancient ditch attract considerable attention. One of these, on Kauai, takes water from the Waimea River and delivers it to the taro beds near the town of Waimea. Water from this ditch probably contributed to the plantings which Captain Cook reported on the day of his first landing. Native legend, however, carries the history of this stream back to the days of the Menehunes. These creatures, somewhat analogous to the Brownies of other folklore, seem to have had a remarkable capacity for work provided that they might work only at night and leave unfinished any endeavor which could not be completed before sunrise. The construction of the Waimea "auwai," or ditch, is often attributed to these Menehunes, part of the evidence being the peculiarly keyed stones which line some of the lower reaches of the canal. Such stonework is unknown elsewhere in the islands. Apparently this stone lining is the only remnant of an ancient and forgotten civilization. Details of this work are shown in Figs. 2 and 3. The suggestion that the stone lining was the work of a Russian military detachment which occupied a small fort near the mouth of the Waimea River (1817) does not seem to be in keeping with the fact that this ditch was described by adventurers as early as 1798. The site of the stonework is now marked by a bronze plaque giving part of the legend of the Menehunes' activity.

Another bit of construction which gains considerable interest, due to the labor involved and not to age, is a tunnel driven through 200 feet of lava near Niulii, on Hawaii. Here the drilling was accomplished from vertical shafts 10 feet apart and driven to proper line and grade. Williams (24), who describes the tunnel with its stone-faced diverting dam in *Thrum's Annual* (1919), sets the date of construction as between 1823-1849. Since steel stools and blasting powder may have been available at this time, the construction need not have been extremely difficult. Many observers, however, date the tunnel much earlier than the time of the arrival of travelers and adventurers who might have supplied such aids to construction. It is often said that the tunnel must have been drilled by the use of fires built in the headings until the rock was heated, and then quickly doused with water. In such an event the patience and engineering resourcefulness of the workmen must have been considerable.

Still another auwai, much more recent than either of those noted above, could be traced in Nuuanu Valley, on Oahu, until improvements in that part of Honolulu essentially obliterated it.

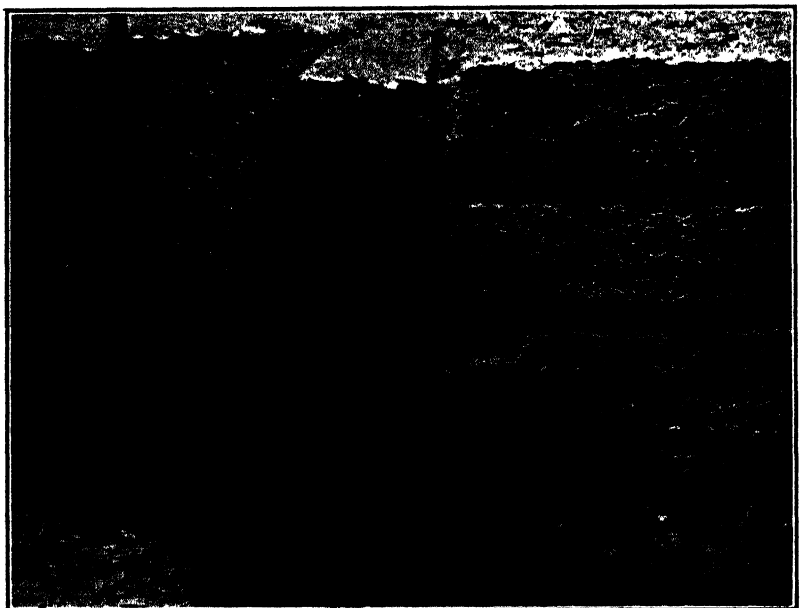

Fig. 2. Stone lining of the so-called "Menehune Ditch," Waimea, Kauai. The faced stone of this lining is found only in this ditch. (Photograph from the Bishop Museum.)

Fig. 3. Another view of the lining of the "Menehune Ditch." Some archeologists consider this stonework a relic of a prehistoric civilization on Kauai; others believe that Russians from a fort at the mouth of the Waimea River in about 1817 were responsible for its construction. (Photograph from the Bishop Museum.)

Irrigation Organization

No account of the simple, although strangely effective, irrigation organization of early Hawaiian people is comprehensive without a basic understanding of the political organization of the time. The conquest of Kamehameha I late in the eighteenth century unified the several independent island kingdoms into a single monarchy of which Kamehameha I was king. Local government was afforded by chiefs, appointed by the king, and holding tenure only by his pleasure. The larger areas controlled by individual chiefs were called "ahupuaas," and although the boundaries of the ahupuaas may have been loosely described, the holding of each chief supposedly carried fishing rights on the sea, taro land on the coastal plains or in the valleys, and forest land in the mountains. This distribution was sometimes accomplished by defining each ahupuaa as an area running from the main divide on the island to the sea and bounded by significant and continuous radial ridges on either side. The water resources of such an ahupuaa would, of course, be sharply defined. Complications were introduced when topography made these ideal boundaries impossible. In some cases streams rising in the domain of one chief would cross his boundary and enter the drainage system of his neighbor. Although such conditions may not have materially complicated native problems of distribution, they have added difficulties to modern interpretation of ancient rights.

Distribution of water within the ahupuaa as well as the granting of homesites and taro patches, called "kuleanas," to commoners, lay in the hands of the chief. Such grants might be withdrawn by the chief and a tenant ejected at the pleasure of the chief, much as the chief himself might be removed at the pleasure of the king. The system was remarkably parallel to the feudal system in Europe.

In spite of the depressing effect that such a system is supposed to have upon initiative, a simple, although a remarkably effective, type of irrigation development was developed. Mrs. Emma M. Nakuina (12) who for many years was an authority on the Hawaiian water code, describes the construction and operation of native ditches in *Thrum's Annual* (1894).

According to Mrs. Nakuina, auwais were constructed at the instigation of the chief of the ahupuaa, the actual construction, of course, being done by commoners. Whether this labor was secured through duress or by promise of participation in benefits is not clear. Sometimes a single auwai served lands in two or more ahupuaas, and in such cases water was distributed to these larger areas in accordance with the number of men provided for construction.

In any event the site of the simple diversion dams seems to have been marked before construction started, and yet Mrs. Nakuina definitely states that construction began at the area to be irrigated and continued up the proposed ditch grade. How an adequate grade might be maintained and at the same time allow the ditch to intercept the stream at a predetermined point without the use of instruments is an interesting speculation. It has been said that a tool, in the form of a long bamboo pole with the nodal tissue removed, was used for this purpose, since water poured into the upper end escaped at the proper rate when the slope was correct. If such a tool were used, it seems clear that the route must have been completely surveyed by this simple means before construction began. The construction of the dam itself and the turning of water into the newly constructed auwai was cause for cele-

bration of religious significance. The desirability of this celebration apparently mitigated against the more simple scheme of building a small dam first and digging downstream ahead of the water on a grade as flat as possible in view of the desired flow and the required point of use. That this more simple scheme was extensively used, despite Mrs. Nakuina's statement, is supported by early observations of G. N. Wilcox, who noted remnants of old ditches near Kilauea, on Kauai, which had patently been dug ahead of a small stream already diverted by a temporary dam. In at least one case this method of construction carried the ditch line into such heavy excavation that the location had to be abandoned and a new route undertaken.

Although the dams were temporary, they were under rather strict control. Apparently no dam was supposed to divert more than half the stream flow, under penalty of destruction by water users below. But if properly constructed a dam became secure from malicious tampering. The penalty for wilfully breaking a dam was death, the culprit's body being used in the necessary repairs as a warning to others. For this punishment there was no reprisal unless, as Mrs. Nakuina naively explains, the culprit was of consequence. In such a case civil war might ensue.

Although the chief of the ahupuaa was master of all the auwais within it, details of administration were delegated to an appointee of the chief, the konohiki. His duties were varied and important. In cases of a cooperative venture between

Fig. 4. An early auwai in Honolulu. This ditch on the Ward place was probably supplied by a spring near King street. (Photograph from the Bishop Museum.)

neighboring ahupuaas, the konohiki of the major area became water master of the canal and divided the water between the two areas in proportion to the number of men furnished. Details of the method of division are not clear in Mrs. Nakuina's account. Apparently distribution was on the basis of time of flow, since no method of measurement is recorded. Moreover, the konohiki was responsible for internal distribution to the taro patches themselves as well as for the maintenance of the system. Users of water from an auwai were subject to call by the konohiki for maintenance work, the penalty for failure to comply being a withholding of water from the taro of the delinquent. The rapid deterioration of the kuleana in such a case might readily lead to eviction by the chief.

Distribution of water to the lands of the kuleana holders was usually on the basis of time, small areas using almost the entire flow of the auwai for a few hours, while larger tracts carried rights for several days. Apparently time was measured by the position of the sun during the day and the stars at night.

Although Mrs. Nakuina makes no mention of other methods of distribution than that noted above, Judge Perry (14) suggests that others were used to some extent. Possibly these alternative methods were in early use and gave place to the more common distribution, as described by Mrs. Nakuina, when the demand for water, due to increased cultivation, required a more conservative practice. One of these alternative methods involved the delivery of the entire stream to a large tract during daylight hours, while night water was supplied to a neighboring tract of equal size. When all small taro patches within the larger areas had been served, the procedure was reversed and the delivery continued. Under other conditions, presumably those of abundant water supply and limited demand, the upper patch received as much water as needed without regard to time. When the operator of this patch was satisfied the next lower was served in a similar manner until all areas along the auwai had been supplied. The procedure was then repeated. Judge Perry also notes cases in which some patches were supplied by overflow and seepage from higher lands and not directly from any watercourse. In any case the distribution seems to have been based upon the idea of rotation and not continuous delivery, although a continuous flow seems to be ordinarily used for taro irrigation in modern practice.

Several of the conditions of the ancient code form interesting parallels to the best features of water law as developed in western United States. Beneficial use of water in the hands of the commoners was essential to continued delivery under the early Hawaiian code as it is among western states operating under the doctrine of appropriation. Compulsory maintenance work on the auwais under the direction of the konohiki, with the threat of refusing delivery, with possible dispossession, is at least analogous to maintenance assessments or water tolls in modern irrigation development, while the powers of the konohiki in rationing water during periods of scarcity are parallel to those of water masters on some important streams in western America. Furthermore, the delivery of water upon the basis of labor contributed in the construction of the auwai is suggestive of the distribution of modern costs upon the basis of benefits received, a method frequently used in drainage ventures. From the nature of the political background and the consequent lack of land titles, no idea of riparian rights needed consideration.

It is evident that the simple water code outlined above might and probably did work unjustly upon commoners out of favor with the chief and his konohiki. In fact a law aimed toward the correction of some of the abuses of the old system is published in the *Laws of 1842*.

In translation this interesting law is worded as follows:

> In all places which are watered by irrigation those farms which have not formerly had a division of water shall, when this new regulation respecting lands is circulated, be supplied in accordance with this law, the design of which is to correct in full all those abuses which men have introduced. All those farms which were formerly denied a division of the water, shall receive their equal proportion. Those bounties which God has provided for the several places should be equally distributed in order that there may be an equal division of happiness among all those who labor in those places. The allowance of water shall be in proportion to the amount of taxes paid by the several lands. . . . . That the land agents and that lazy class of persons who live about us should be enriched by the impoverishment of the lower classes, who with patience toil under their burdens and in the heat of the sun, is not in accordance with the designs of this law.

Since water in Hawaiian streams was usually sufficient for the irrigation of valley and flood-plain lands in taro, even at low-river stage, the surplus waters find scant notice in the early water code. The heavy construction required for the utilization of these waters upon near-by slopes was beyond the engineering resources of the time, resourceful as the natives may have been. Apparently such water was allowed to follow its natural course to the sea. Patently this water belonged to the chief, at the pleasure of the king, and in all logic the legal ownership passed to the chief along with the ownership of land upon his completion of the legal requirements of the Mahele. The adjudication of these rights, commonly called the "konohiki rights," during and after the Mahele, forms one of the most interesting chapters of modern Hawaiian water law.

Early Taro Culture

Although all early travelers note the culture of sugar cane, yams and bananas in addition to taro, it seems clear that taro alone was irrigated, except that other plants established along the edges of the patches or on the banks between them might benefit by seepage water. As has been indicated, some early accounts emphasize the great height of the banks and note that some were wide enough to allow for a road or rows of banana plants on their tops.

Such descriptions of taro production are apparently incomplete and emphasize a method of culture which was not common except in particular areas. Two methods must have been in general use. One practice was employed when spring water under significant pressure head was available, while the other, involving low levees and shallow depths of submergence, was used with the more common stream diversions. Both Campbell (4) and Corney (5), who describe the high banks and great depth of water in taro production, had most of their agricultural experience near Pearl Harbor, on Oahu, where natural springs were numerous.

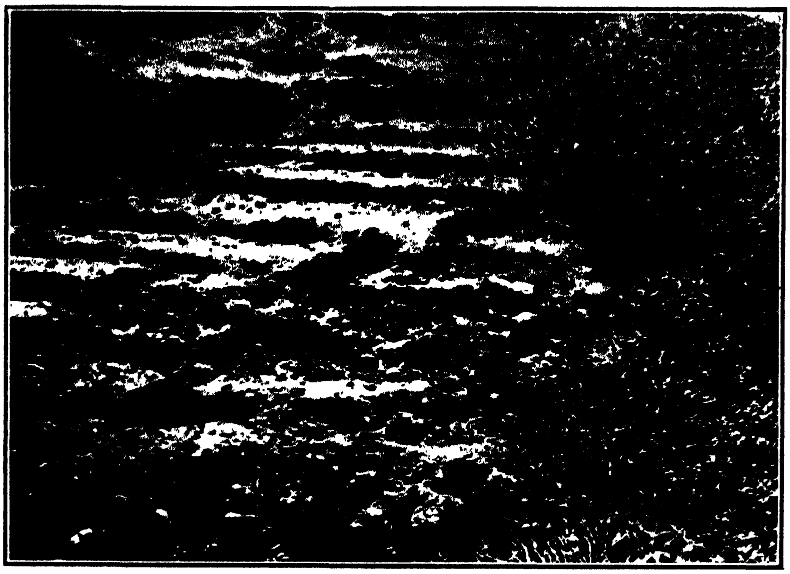

Fig. 5. Remains of taro patches, Awaapui Valley, Kauai. The black wall in the background is the face of an ancient heiau. It is fifteen feet high. (Photograph from the Bishop Museum.)

Fig. 6. Another view of the taro beds in Awaapui Valley, Kauai. These patches on the cliff over the sea were in unusually difficult topography. (Photograph from the Bishop Museum.)

Professor John Wise, of the University of Hawaii, is authority for the statement that natural spring waters were utilized by surrounding the spring with high, water-tight levees, which enclosed about half an acre of ground. Piles of dirt thrown up inside these basins provided planting area for the crops to be grown. Bananas planted on the tops of the piles secured adequate moisture without submergence while sugar cane and yams planted at lower elevations and, of course, nearer the water level, supposedly secured moisture in accordance with their needs. Taro planted still lower on the slopes was partially submerged. This method of culture was necessarily limited to areas in which natural springs occurred under such conditions that a two- or three-foot head might be maintained.

Flat culture was much more common. When this method was used low levees were thrown around conveniently shaped areas of land and water admitted from the neighboring auwai. Apparently water was admitted to each basin from the one above it, if not from the auwai itself, drainage from the last patch finding its way into the original stream or another ditch.

Few remains of the high banks, necessitated by the common practice when springs were used, exist at present. In most ancient taro beds the levees are less than three feet high and relatively narrow. Perhaps the best unspoiled taro patches at present are to be found in the Kalalau Valley, on Kauai. This valley, although it once supported a large community, is small and until recently has been inaccessible except by sea. Landing from boats is often hazardous. Consequently, no modern use, except for cattle grazing, has been made of it. The old taro banks found here are much smaller than those reported by Campbell (4) and Corney (5). In no instance were banks more than three feet high discovered, except in cases where the topography demanded distinct terracing. Nor were the tops of the banks of significant width. Only the stonework in the old levees remains, the earthen facing, as described by early travelers and required in view of the construction, having disappeared. The remains of ancient taro patches in Awaapui Valley on the Napali Coast of Kauai are shown in Figs. 5 and 6. Fig. 7 shows similar evidences in Makahua Valley, Oahu.

Some authors refer to the taro patches as beds which are excavated to a depth of two or three feet in place of enclosing small areas by banks built upon the normal ground surface.

"Haole" (8) describes early taro production somewhere near Kaneohe, on Oahu. Here the bed method was used, their newly leveled bottoms having been beaten with coconut stems to aid in holding water. As in present times, planting material came from suckers from one year's growth or from tops of harvested taro.

"Haole" seemed impressed with the intensity of production at Kaneohe, saying that "forty square feet of land planted with kalo will afford subsistence for one person for a whole year." The author probably means an area forty feet square, since this interpretation justifies his additional statement that "one square mile planted with the same vegetable will feed fifteen thousand one hundrd and fifty-one persons for the same length of time." In his computation he allows considerable area for paths and ditches.

Fig. 7. Taro patches in Makahua Valley, Oahu. The height of the terrace faces may be judged by the figures. (Photograph from the Bishop Museum.)

Fig. 8. Taro beds. Although this photograph is recent, it represents an ancient practice. (Photograph by K. B. Tester.)

Campbell's (4) mention of the actual production of the crop concerns the labor involved and not the value of the product. "This mode of culture," he said, "is particularly laborious and in all operations those engaged are almost constantly up to the middle in mud. Notwithstanding this, I have often seen the king working in a taro patch." Such a statement must have been based upon observations on the type of culture used with natural springs.

Taro production in the early days was a continuous operation, harvesting and replanting being determined primarily by rate of consumption by the kuleana holder and his dependents. Supplies of mature tubers were removed from the beds as needed and carried away from the growing area for cleaning and preparation as poi. Replacements of planting material in the beds provided for a continuous supply.

Whether the modern pathological trouble of taro root-rot was a significant factor in early production seems doubtful. Some authorities believe that the causative organism is some variety of the nematode Tylenchus, which also seems to have played a part in the so-called failure of the Lahaina variety of sugar cane. Whether there is any connection between the rapid spread of Lahaina cane in later years and the present menace of taro root-rot, in view of the similarity of the organisms involved, is not known. In any event, the early harvesting methods would tend to keep such a soil-organism under control if it were present. Under modern practice, the irrigation supply is usually continuous if possible, one reason given for such a type of delivery being that taro rot is retarded by the abundant use of fresh water. The reason for this control is unknown. As has been stated, the delivery of irrigation water to the ancient patches was usually by rotation.

Early Sugar Culture

The present sugar industry found its beginning in an atmosphere of indefinite land titles, ill-defined water rights, and a native superstition which endowed certain individuals with the powerful agent of tabu. The first two of these obstacles were removed through the action of a wise and generous king, while the power of the tabu, being of local religious origin, naturally declined with the importation of foreign labor. Consequently, the history of the sugar industry may well be divided into two chapters, the first extending to the Great Mahele of King Kamehameha III, by which action the titled ownership of land, and presumably water, by individuals was possible, while the second carries the history from this point to the present.

The earliest travelers to Hawaii note the presence of sugar cane, yet the use of the word "indigenous" in this connection may be subject to criticism. Since the early cane was similar to that found elsewhere, it is possible, if not probable, that planting material was brought to the islands by the early Polynesian settlers, whatever their origin may have been. In any event, the plant was widely distributed at the time of the first written mention. Since it formed a significant part of native food, this wide distribution is not surprising. Willfong (25) is authority for the statement that wild cane was planted in much unusued land after the wars of Kamehameha I in order that an abundance of food might be available for travelers.

Apparently such cane was eaten in the stick, the first extraction and partial refining being credited to a Chinese who came for sandalwood in 1802. The simple mill and boiling equipment seems to have been brought from China and used for a short time on the island of Lanai. The apparatus was subsequently disassembled and returned to China, presumably in the same ship that brought it to Hawaii.

This early activity on Lanai seems to be of only historical significance, since no further record of sugar manufacture is noted until 1819, when Francisco de Paula Marin is said to have made sugar in Honolulu. An Italian is credited with sugar manufacture in Honolulu in 1823.

In the meantime there seems to have been some activity on Maui, for in the same year (1823) Antone Catalina and a Chinese, Hungtai, established mills at Waikapu and Wailuku, respectively. It is probable that interest in manufacturing sugar has been essentially continuous in this high-producing area since that date, although this continuity is not demonstrated in the records.

Such early accounts deal entirely with the establishing of crude mills and the preparation of sugar. It is probable that the cane used was native cane growing in the neighborhood and carried to the mill. The first mention of a sugar plantation in the sense that cane was actually planted and cared for with subsequent milling in mind is associated with John Wilkinson, who in 1825 laid out a coffee and sugar plantation in Manoa Valley, on Oahu. Apparently no difficulties were encountered in growing the cane, although operations were severely handicapped by lack of capital and suitable tools. Wilkinson's death, prior to the first cane harvest, curtailed all activity and the plantation soon wasted away for lack of care. Another planting in Manoa, planned for the production of sugar and rum, ceased operation in 1829.

In 1835 a Honolulu firm, Ladd and Company, secured tenancy rights to a tract of land near Koloa, on Kauai, for silk and sugar culture. Although difficulties of operation were great and the original company did not long survive, this venture seems to have been the forerunner of the present system of corporation operation.

No land titles were possible at this early date, as has been indicated, and permission to occupy must have been primarily one of tolerance. Moreover, no tools for sugar production were available, and early accounts tell of plows being drawn by natives, although such statements are sometimes questioned. Labor troubles were also present, not only because it was difficult to interest the easy living natives in the hard work required, but also because of the relics of the declining tabu system which still prevailed. Kahunas or native witch-doctors might, and doubtless did, forbid work on certain days by declaring such effort *tabu*. From such a system the plantation seems to have had little recourse. Crudities in methods, resulting in low recovery of sugar and sugars of inferior quality, were also factors adding to the difficulties of these pioneers. Two mills were established and abandoned at Koloa prior to 1840. A third was built in 1841.

In spite of these handicaps, Ladd and Company demonstrated the possibility of sugar production on a commercial scale. Thrum (21) gives the production for 1838 as 5,039 pounds of sugar and 400 gallons of molasses. The arrival of M. Victor Prevost, an experienced sugar manufacturer, at about this time, soon brought about an improvement in quality of the product from Kauai.

It is natural that the activity of Ladd and Company on Kauai should stimulate interest in other districts. Twenty-two mills were in operation, or soon to be erected, in 1838, although it is clear that such mills could have had little similarity to their modern highly efficient successors. Willfong (25) describes several typical mills on Maui as he observed them in 1849. Those used on the large percentage of the twenty-two locations noted above were probably no more elaborate. According to Willfong, the entire factory consisted of a battery of wooden rollers, perhaps 18 inches in diameter and two feet long, mounted vertically and driven usually by animal power, and a series of three open try-pots bought from visiting whalers. Presumably the cane was fed by hand, the juice being simply concentrated by successive boiling in the open kettles. He makes no mention of the processes leading to crystallization and sugar recovery. In fact, he stresses the profits resulting from the sale of the thick syrup to whalers, presumably for rum-making. The cane trash was usually insufficient fuel for the boiling down, indigo being used as a supplemental supply at Lahaina. The area cleared by this means was subsequently used for the first planting of a supply of seed cane brought by Captain Edwards, of the whaleship George Washington. This cane was subsequently called "Lahaina."

Although it is doubtful that the simple mills described by Willfong and called "screeching nuisances" by President Lee (9) of the Royal Hawaiian Agricultural Society, could have produced the amount of sugar credited to the Ladd and Company plantation in 1839, it is probably true that most of the mills of the period were of about that order. No great capital was invested in machinery, and what machinery was necessary was readily portable and seems to have changed hands rather frequently. Moreover, most mills seem to have depended upon

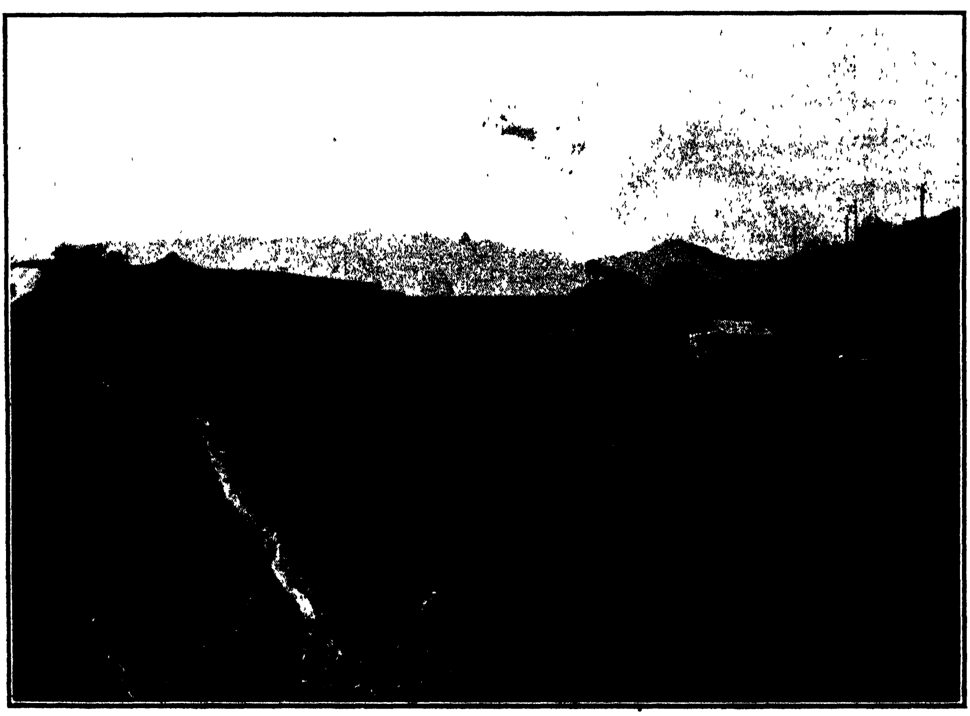

Fig. 9. The Waiawa Valley, Oahu. Although this valley has long been in rice, it is the site of the first venture in the irrigation of pineapples in Hawaii. (Photograph by the author.)

native wild cane—little capital being tied up in a growing crop. References to irrigation in the accounts of the early history of sugar are conspicuously absent. It is highly improbable that any irrigation was done by Ladd and Company, while the cane milled at Lahaina was only incidentally watered, since it was grown only on the banks of the taro patches.

Because of the simplicity of the mills, the low cost of cane production and no investment in irrigation works, the early business of sugar production seems to have been extremely flexible. Mills were established, produced sugar or syrup for a few years, and then were abandoned or moved to a new site if conditions seemed more favorable in the new location.

Another factor making for flexibility in the early days of sugar production lay in the inability of the producers to own land. As has been indicated, ownership to all land lay in the hands of the king, and its uses were permissive only. It is clear that such a condition could not have fostered a progressive and highly specialized agriculture.

The effective transition from essentially feudal conditions, which existed since ancient times, to surety of land titles in individuals within only about ten years, is a splendid commentary upon the wisdom, farsightedness and generosity of King Kamehameha III. The steps leading to this remarkable decree of the king need not be considered here, since the political and social background of the time as well as the simple but effective procedure by which land titles were brought into the hands of individuals is ably discussed by Alexander (1). It seems clear, however, that the necessity of fostering and encouraging the sugar industry was not a vital factor in the movement.

Moreover, it is strange that the efforts of the Land Commission during its short but active life under the authority of the Act of 1846 should have been directed entirely toward confirming claims for land titles. No recognition of the water right previously enjoyed by the land was made either in the text of the act authorizing the commission or in its actions. However, it seems to have been tacitly understood that the granting of title to a particular parcel of land to an individual carried with it the right to the usual amount of water from the usual source. It is hardly surprising that complications should have arisen.

A means of settling these inevitable disputes was provided in 1860 by the appointing of three persons in each election district to act as Commissioners of Private Ways and Water Privileges. In addition to other things, the duties of these commissioners involved determining all controversies respecting rights to water between individuals and between individuals and the government. A right to appeal to the Circuit and Supreme Court was available. In 1888 the commission was reduced to a single member and appeal limited to the Supreme Court only. In 1907 the office of commissioner was abolished and its duties transferred to the circuit judges.

The findings of the commissions and judges and decisions of the courts have developed a code which is simple to understand in its broad principles, entirely operable under the topographic conditions of Hawaii, and still is entirely different from the English conception of riparian rights and the doctrines of appropriation

and beneficial use so widely used in western America. The litigation involved in the development of Hawaii's water resources has been comparatively small.

The metamorphosis of the ancient system of water distribution into a modern workable water code has been sure and methodical. Basic conceptions are, in general, clearly defined either by the original premise that title to necessary water passed to the individual when he received title to land at the time of the Mahele, or by subsequent decisions by the courts.

In general, the present code holds that title to water originated at the time of the Mahele. Commoners at that time secured title to the water required for the continued production of their taro patches, while a minor chief holding an ahupuaa came into titled ownership of all waters rising upon it, less such water as the holders of kuleanas required under the old practice for domestic use and for the cultivation of their taro. Water originating upon government land was subject to the same limitation.

Moreover, it has been uniformly held that water passes with the land in sale, although there is no necessity of utilizing such water upon the land to which it was originally appurtenant, provided that by its transfer to other areas no injury is done to others who have a legal claim to water so diverted. Most Hawaiian streams seem to have been only incompletely utilized, in native taro production the unused surplus being the property of the person, usually the local chief, who acquired title to the ahupuaa in question. Rights to the surplus water, or the konohiki rights, form the controlling point in the ownership and distribution of irrigation resources. A large part of modern development has been made by securing such rights by purchase of the ahupuaa and the subsequent transfer of available water to areas which in early days had never been irrigated. Difficulties, of course, arise in the determination of the amount available for diversion in view of the ancient and well-established rights below the point of diversion. The same indefiniteness exists when old kuleana rights are purchased. In general, the amount of water involved in such cases has been determined upon the testimony of local witnesses, although the actual measurement of the water required for satisfactory taro production under local conditions is now a more common method. Waters arising upon government lands are leased for definite periods upon the terms secured at a formal auction.

Naturally, some aspects of the general conception require special consideration. In general, the boundaries of the ahupuaas were so largely governed by ridges and radial mountain spurs that the water resources of each might be readily determined. In some, however, the boundaries were quite arbitrary, and water rising on one ahupuaa may flow through another into the sea. In other cases, waters may rise partly on one ahupuaa and partly on another, the combined flow crossing a third before reaching tidewater. Questions involved in the ownership of such waters have not as yet been settled. Moreover, some authorities seem to believe that kuleana holders should be allowed some proportion of the surplus or freshet waters, since such waters, in early days, were used abundantly and with good results in native taro culture. Nor has the landowner's rights to ground water been adequately defined.

In spite of the comparative simplicity of the Hawaiian water code and its

success in developing the water resources of the Territory, the legislature in 1915 authorized the Governor (38) to appoint a commission to examine the water resources of the Territory and to "draft such legislation as may be deemed necessary by it to serve the best interests of the people of Hawaii." This commission, composd of G. K. Larrison, A. G. Smith and T. F. Sedgwick, secured the services of A. E. Chandler, for many years a member of the State Water Commission of California, and a well-known authority on water law. In his report, Mr. Chandler advised against additional legislation, apparently finding the local laws adequate for all future contingencies.

Developments Since the Mahele

Although the Mahele of 1848, with its promise of surety of land titles, should apparently have stimulated individual enterprise, the Hawaiian sugar industry declined rapidly immediately thereafter. A period of low prices beginning in 1852, coupled with a great drought in 1851, drove many of the smaller enterprises out of business. By 1857 the number of plantations had been reduced to five. Two of these, Lihue and Koloa, were on Kauai; two, the East Maui Plantation and one known as the Brewer Plantation, were on Maui; and the fifth was on Hawaii near Hilo. There is no record that any of these were irrigated plantations.

It is perhaps only natural that the promised, although as yet untried, security of land title, together with a devastating drought, should have turned attention toward irrigation. Eight years elapsed, however, before the first canal for the irrigation of cane was begun. During this period, W. H. Rice, for ten years associated with the Punahou School in Honolulu, became manager of H. A. Peirce and Company at Lihue. Although of New England ancestry, Mr. Rice early sensed the opportunities of irrigation and is reported as having remarked upon the fertility of the land of Oahu, "could water be applied," within only a few weeks after his arrival. Practical information in methods of irrigation and its possible results under local conditions was gained during his tenure at Punahou, since the school was largely self-sustaining as far as garden products were concerned. Abundant water for the gardens was secured from Punahou Springs and carried through the grounds in small ditches. Among the other plantings was a small block of irrigated sugar cane, located between the present site of Dillingham Hall and Punahou street.

With this background it is hardly surprising that Mr. Rice should early turn his attention to the possibilities of irrigation at Lihue. Here droughts seem to have been particularly severe. At times entire fields were cut back to the roots in order that the ratoon crop might take its chance in turn.

The first canal was not long nor costly, by present standards, but in view of the lack of tools and inexperience and the general lack of sympathy by Mr. Rice's associates, it was a tremendous venture. The canal is reported to have been eleven miles long and to have cost $7,000. Ethel M. Damon (7) gives April, 1856, as the time of beginning of construction. Letters of the period indicate that water was actually admitted to the Lihue field on August 16 of the same year. An old photograph of part of the first ditch on Kauai is shown on the cover of this issue. Although considerably enlarged, this canal, through the German Forest, follows the location of the Rice Ditch. The original photograph was taken between 1880 and 1890. The writer is indebted to Miss Damon for permission to use this print.

The period of drought seems to have continued, however, and a brief statement in *The Transactions of the Royal Hawaiian Agricultural Society* for July, 1856, indicates that continued dry weather made it impossible to divert water from the stream originally intended and that the canal was being extended to a "large and constant stream nine miles away." Other difficulties presented themselves, for a short note in the *Pacific Commercial Advertiser* for July 9, 1857, reports that the work was not yet completed, although great hopes were had for the following year.

Apparently these hopes were realized, for with the completion of this ditch the principle of gravity irrigation of Lihue and Grove Farm lands became established. Further developments under the capable hands of Paul Isenberg and G. N. Wilcox removed irrigation from the realm of speculative venture and established it upon the unquestioned basis of engineering principles.

In spite of the wealth of detail furnished by Miss Damon (7) with respect to the construction of these early canals, we find little in the records with respect to the actual distribution of water in the cane and the modifications of culture which must have been involved. It is hardly surprising, however, that the records are fragmentary. The Royal Hawaiian Agricultural Society, which began its short life in 1850, became inactive in 1856, after publishing seven annual volumes of *Transactions* which have become most valuable as source books. Sugar production was not generally considered of outstanding importance during the period of its publication, although Judge Lee (9), the founder, mentions "our great staples of sugar and coffee" in his address during the organization of the association. As has been indicated, the society discontinued publishing its proceedings at about the time that irrigation was being recognized.

However, casual phrases lifted from some of the addresses of annual chairmen indicate that the desirability of irrigation was at least being considered. For example, in the second volume of the *Transactions,* the Hon. Luther Severance (15) forecasts a time when " . . . the mountain stream must be carried in canals or aqueducts or lifted in small jets by the hydraulic ram. . . ." Two years later (1853) the annual address by John Montgomery (11) sounds a word of warning against the extension of irrigation and urges deep plowing and constant cultivation as a substitute. One of his phrases is particularly interesting. Here he says, " . . . the value of which (surface irrigation) I consider very questionable, as the soil saturated with a stream of water in summer and suddenly dried by a vertical sun, becomes so baked and consolidated as to be impervious to the roots of ordinary plants; and for this reason I have abandoned it." Where Mr. Montgomery had practiced irrigation is not clear.

It is not surprising that the possibilities of irrigating a crop so different from the widely grown taro should have escaped recognition at this early date. Large scale irrigation development in continental United States is commonly assumed to have begun with the Mormon migration to Utah in 1847. In view of the origin of the pioneers in Hawaiian irrigation and the distance involved, it must be assumed that the local development of irrigation, as an aid in commercial agriculture, was quite independent of that in Utah, and essentially concurrent with it.

Another interesting comparison between early Hawaiian development and that in continental United States lies in the debates over the virtues of irrigation which took place in each area some time before that practice became a recognized factor in crop production. The remarks of Judge Lee and Mr. Montgomery in 1851 and 1853 have already been mentioned. Discussion of the place of irrigation in agriculture in the United States was most bitter immediately prior to the passing of the Reclamation Act in 1904, almost forty years after the unquestioned success of gravity irrigation on Kauai.

The end of the active life of the Royal Hawaiian Agricultural Society in 1856 was practically concurrent with the development of the first gravity canal for sugar cane irrigation. By 1883, when the Planters' Labor and Supply Company was formed and its journal began the account of the development of the sugar industry, the economic justification of costly irrigation works for sugar cane had been established. The period of greatest interest in a study of the irrigation development in Hawaii is not covered by continuous printed record in any agricultural publication, although Thrum's Annual, published yearly since 1875, provides much information. References to water development in Mr. Thrum's Annual "Retrospections" are particularly illuminating.

But the period between 1856 and 1878 must have been one of considerable activity both in the organization of new plantations and in the development of irrigation resources by those which already were in operation. This transition was particularly well marked in the operations at Lahaina. Willfong's description of Parson's old mill at Lahaina has already been mentioned together with his statement that cane production was only incidental to taro growing. Moreover, the mill seems to have been moved to Makawao in about 1850. Apparently sugar milling was discontinued at Lahaina at this time.

Within the next twenty years significant changes took place, for in 1870 the partnership of Campbell and Turton, which for many years had been developing and operating a large tract of sugar cane land at and near Lahaina, was dissolved, control of the plantation ultimately passing to the Hackfeld agency. Since irrigation is essential to cane production in this region, it is evident that irrigation development must have been a significant and vital part of the company's program. Little is known of this development or of the method used for the actual distribution of water to the growing cane.

Whether or not development at Wailuku had been continuous since the early endeavors of Catalina and Hungtai, it is clear that three plantations were in existence near the mouth of Iao Valley in 1868 when Willfong became manager of the Wailuku Plantation. It is apparent, too, that irrigation was vital to all three, for Willfong (25) reports that "division of water (from the Wailuku River) during dry seasons, caused much quarreling which resulted in heavy law suits." Willfong also reports that he tried an "experiment" in 1875-76 which involved trenching before planting and striking a water level for each trench cut for placing the seed. He simply remarks that the method worked well but gives no further details, nor does he give any description of the method in use before that time. The similarity between Willfong's method and the general modern practice in the irrigation of cane is apparent.

Although developments at Lihue as well as at Lahaina and Wailuku were significant in view of the fact that they demonstrated the benefits to be derived from irrigation, they seem to have been relatively small projects for the most part, involving neither large capital nor great engineering resourcefulness, although the labor involved must not be minimized. In general, waters were utilized on the flood plains of their normal course. Since little is recorded as to the construction involved in the early works at Lihue, and nothing concerning those on Maui, it is probable that they were simple in design and employed no principle unknown to the natives.

A new chapter of development begins with H. P. Baldwin and S. T. Alexander, who demonstrated the feasibility of carrying water from regions of high rainfall across the difficult topography of East Maui for delivery to the fertile sun-soaked plains near Paia. Born of missionary parents at Lahaina in 1842, Mr. Baldwin must have had ample opportunity to judge the benefits of irrigation during his early life. Moreover, after graduating from Punahou, he returned to Lahaina in 1863 to work for an older brother, Dwight, who was growing cane for the Campbell and Turton mill. Although Baldwin's biography (3) contains no mention of irrigation during his cane-growing experience at Lahaina, it is highly probable that artificial watering was an essential part of the operation. It is also probable that further experience was gained during his service as head luna at Waihee.

It is clear, however, that the plantation organized by Mr. Baldwin and Mr. Alexander at "Sunny Side," above Paia, in 1870 was not irrigated. The first few years of this plantation were unprofitable, due, primarily, to scarcity of rainfall.

Since the abundant water resources of East Maui were not far away in miles, although remote because of engineering difficulties, a scheme of carrying this water to the lands around Paia soon suggested itself. This water, being under the jurisdiction of the government was secured by lease which ran in favor of a group of closely knit planters in the vicinity. In view of the difficulties involved, it is interesting to note that only two years were allowed by the conditions of the lease for completion of the project. If uncompleted by September 30, 1878, rights to the water were to revert to the government. It was initially estimated that the cost would not exceed $25,000. Financing was done by Castle and Cooke, of Honolulu. The complete cost greatly exceeded the estimate.

The difficulties of construction in view of number of men employed and the necessity of feeding them in remote camps, the organization required to order and install the great pipes used for the siphons and the building of flumes from native timber show the will and resourcefulness of Mr. Baldwin, who acted as superintendent of construction for the siphons and flumes, and Mr. Alexander, who directed the earth work. The work was completed barely in time to save the lease in view of its time clause. The reported cost was $80,000 in place of the estimated $25,000.

The effect of this work has been summarized by Arthur D. Baldwin (3) in his biography of his father. "The building of this ditch," he writes, "was an event of the utmost significance, not only to the island of Maui ~~but~~ to the whole group. In all the islands similar conditions existed, which the progressive planters began

to meet in the way which had been shown by Alexander and Baldwin on Maui. The results on that island have been impressive. The Spreckels, Lowrie, Koolau and other ditches have followed the Hamakua ditch, and Central Maui, which once was a bare waste, is now one of the most productive spots on the globe, supporting a prosperous population where formerly little existed besides the razorback hog, prickly pear and wild indigo."

The building of the Hamakua ditch of Alexander and Baldwin was quickly followed by another from the same general region built by Claus Spreckels. The Spreckels ditch is reported to have been the first step in a great scheme to water the Maui plains with the combined water resources of the East Maui and West Maui mountains. The estimated cost of the project was half a million dollars. Water was to be supplied to 17,000 acres of Crown land in Central Maui (37); subsequent developments have completed this plan.

These engineering successes upon Maui were followed by a few years of depression in the sugar industry, probably due initially to labor troubles, and which continued through 1887 because of an unsettled political condition. Although a ditch was proposed for the Hamakua district on Hawaii in 1883 (26), no significant gravity development was inaugurated during the period. However, the period was marked by development of interest in underground water resources and the discovery of an unquestioned artesian basin at Honouliuli.

James Campbell has been mentioned as one of the pioneers in irrigation and sugar production on Maui. With the returns from the sale of his equity in the Pioneer Mill Company, Mr. Campbell purchased two large tracts of land on Oahu, one at Honouliuli, including the lands of the present Ewa Plantation, and another more distant, part of which is now included in the Kahuku Plantation. For several years these areas were operated as stock ranches, water for the cattle on the arid plains being secured from natural springs.

In 1879 Mr. Campbell made a trip to California and seems to have visited the Santa Clara Valley in that state during the excitement caused by the discovery of underground water which might be tapped by shallow, inexpensive wells. At any rate, Mr. Campbell soon returned bringing with him a well driller named Ashley, from California, and his light, hand-operated well rig. This crude device was immediately set up close to the present site of Pump 1, of the Ewa Plantation Company. Artesian water, in the sense that water flowed over the top of the casing, was secured from a shallow hole. One of Ashley's wells, still in daily use, is shown in Fig. 10.

Other wells were at once proposed and in 1882 McCandless Brothers, of Honolulu, were engaged to drill a more pretentious well on the plain between the present mill site and Pump 1. Water was also found at this location, but due to the surface elevation, free discharge was not secured. The well was immediately enlarged into a vertical shaft and a steam-driven pump installed, the water being used for stock pastured on the higher lands. With the successful completion of another well in January of 1883, near the present Pump 3, the existence of extensive underground water resources seemed demonstrated.

The colonization of the Honouliuli lands by sugar, rice, grape and fruit growers was proposed in 1886 by a development company headed by James

Fig. 10. Ashley's second artesian well at Honouliuli, Oahu. The first well is now capped and is in Field C of Ewa Plantation Company. This well supplies water for stock, the purpose for which it was drilled. (Photograph by the author.)

Campbell as owner and B. F. Dillingham as general manager. According to the prospectus issued at the time (27) small tracts of land were offered for sale for from $100 to $200 per acre for the best land, while grazing land was offered for $25 an acre. The conditions of sale were similar to those in force on many of the best land subdivision schemes of the present day. One of these conditions was that all tracts were to be substantially fenced, the company supplying the material and the buyer doing the work. Other restrictions were that a dwelling be built within six months and that a certain number of trees be planted to each acre purchased. Ten per cent of the purchase price was required upon the signing of the contract, the remainder being due upon a plan of deferred payments. Apparently each settler was expected to drill for and to develop his own irrigation water; at least there is no mention of a central irrigation agency in the prospectus.

Attractive as this plan of purchase should have been, in view of subsequent development, it does not seem to have been received with much interest in 1886, and few, if any, sales were consummated under it. Sometime prior to 1889, B. F. Dillingham authorized an extensive survey of the practice of irrigating sugar cane in Hawaii and of the water resources of the Honouliuli and Kahuku areas by the firm of Schuyler and Allardt, consulting engineers, of San Francisco. The report of this survey (16) reviews the practice of sugar irrigation as of that date and gives the first printed record of the amount of irrigation water required for the cultivation of cane at Hamakuapoko, Puunene and Wai-

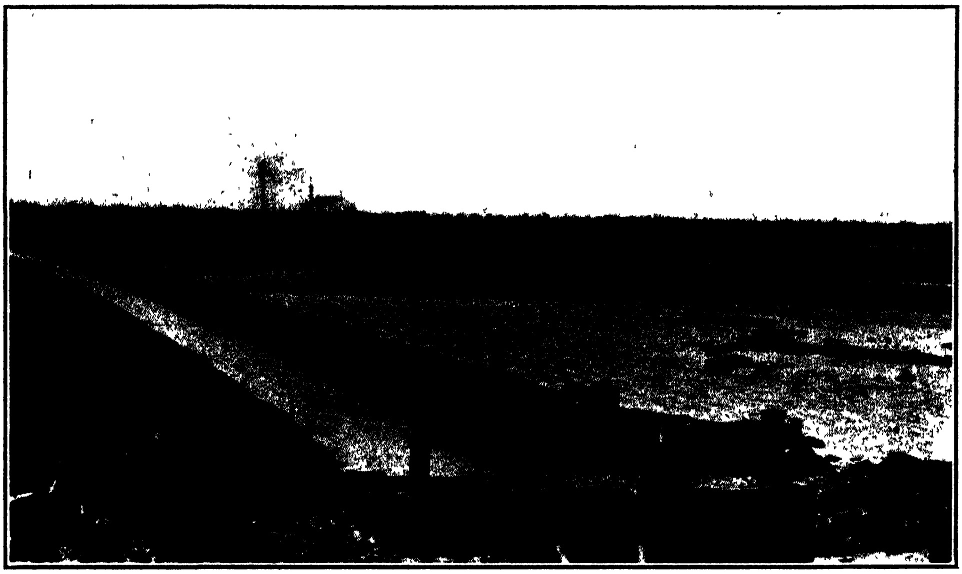

Fig. 11. Flooding of cane at Ewa Plantation Company. This practice, the forerunner of the modern border method, was used at Ewa when flat slopes made the standard contour line impractical. (Photograph by Ewa Plantation Company.)

luku on Maui and the Kekaha plantation on Kauai. The authors seem to have made their own measurements, using a current meter. It is interesting to note that the unit of measurement was the cubic foot per second per acre. Mr. Morrison, the manager of the Hawaiian Commercial and Sugar Company, is quoted as saying that sugar land could afford to pay $100 per acre for irrigation water. In conclusion, the authors reported favorably upon the underground water resources of the two areas of immediate interest and encouraged their development by steam pumps. Moreover, they suggested the possibility of developing gravity water near Wahiawa, tentatively locating a canal from their proposed dam site to the Ewa lands.

Although Mr. Campbell must have recognized the possibilities of sugar development upon his new holdings, he seems to have had little desire to participate actively in the work, for in 1890 both areas were offered for sale to, and later leased by, B. F. Dillingham for a long term.

These lands were soon subleased to corporations organized for the purpose of producing sugar. The Ewa Plantation Company was organized in 1890 and the Kahuku Plantation Company shortly after.

In the meantime H. P. Baldwin, while on a tour of Scotland, had secured a long time lease to a tract of land on the island of Kauai and upon his return in 1889 he turned his attention to the organization of the Hawaiian Sugar Company at Makaweli and the development of a supply of water in the Hanapepe Valley. The aqueduct, capable of delivering 60 M. G. D. (million gallons per day) was 13½ miles long, consisting of tunnels, open ditches, flumes and siphons, four of these being carried across the Hanapepe River on substantial iron bridges. Two miles of open ditch section were cut in solid rock. The reported cost was $152,000 (28). Although Mr. Baldwin had had no formal

training as an engineer, his judgment was so good and his experience on Maui so complete that G. F. Allardt, already noted as the associate of J. D. Schuyler, and a consulting engineer of San Francisco, engaged to consider the project before the work was begun, made no changes in the plans (3). The work was completed in April, 1891.

The influence of the new pumping development on Oahu is to be noted in a short account of the Hanapepe work in *Thrum's Annual* for 1892. Here the writer emphasizes the fact that the water was developed "at a cost not exceeding the first cost of a first class pumping plant doing equal duty and pumping 100 feet."

An interesting episode in irrigation development as applied to pineapples is to be noted in 1893, although this promising practice was soon abandoned and essentially forgotten. It is probable that the possibilities of irrigation as applied to pineapple culture were first noted by J. P. Keppeler, who, in November, 1893, irrigated an appreciable area in the Waiawa Valley, on Oahu. Water was secured from shallow wells and pumped to the point of use. The site of Mr. Keppeler's interesting venture is shown in Fig. 9.

The pineapple plants were grown in rows usually straight, but curving when the topography demanded. Rows were about two and a half feet apart, the plants being about a foot apart in the rows. Irrigation was accomplished by running a small stream of water in furrows drawn between the rows. The plants were irrigated every ten days.

Remarkable yields, both in fruit and in planting material, are reported from this area. Mr. Keppeler indicates that fruits weighing from 12 to 15 pounds were common, and that mature fruits were secured in from 14 to 18 months. Since the practice of canning the product locally was still in its infancy, fruits from this area were carefully packed in straw and shipped to brokers in San Francisco. Despite the excellence of the product, the venture was not profitable.

Other growers became interested, however, and the practice of irrigation as applied to pineapples spread slowly into other near-by areas and to Wahiawa, primarily due to the activity of Byron O. Clark. Subsequent developments at Waipahu eliminated the plantings of Mr. Keppeler and his associates at Waiawa, while irrigation may not have been economically essential at Wahiawa. In any event the practice of irrigating pineapples seems to have been short-lived. There is some evidence that irrigation as applied to this fruit was considered on the lands of the McBryde Sugar Company on Kauai at about the same time.

Still another period of depression in the sugar industry set in soon after the incorporation of the two sugar plantations on Oahu and the completion of the Hanapepe ditch on Kauai. Low prices for sugar, due to the McKinley bill, forced some established plantations out of business, while others turned their attention to increasing production upon the areas already under cultivation in place of expanding. Moreover, labor conditions are reported as unsatisfactory.

Low prices and insecure labor conditions soon suggested an agricultural experiment station in which the common problems of the industry might be studied upon a cooperative basis. Such a laboratory was established in 1895 under the able direction of Dr. Walter Maxwell, who resigned from the U. S.

Fig. 12. Waimanalo ditch, Ewa Plantation Company, before lining. Increased appreciation of the value of water focused attention upon the losses which must occur in such ditches. (Photograph by Ewa Plantation Company.)

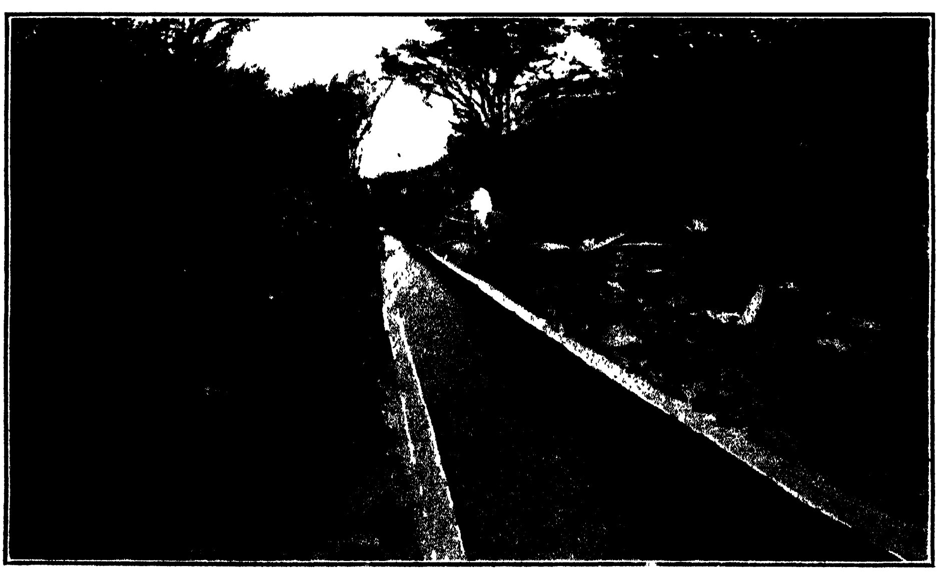

Fig. 13. Waimanalo ditch, Ewa Plantation Company, after lining. In addition to curtailing seepage losses, such linings increase the ditches' capacity. (Photograph by Ewa Plantation Company.)

Department of Agriculture to accept the post. The studies of the newly organized station along the lines of irrigation investigations as well as similar studies by the plantations themselves have been summarized by Alexander (2).

Better conditions for the sugar industry followed the establishing of the Experiment Station. Increased sugar production per acre brought profit to plantations which had lived over the period of depression; the labor situation was improved; new plantations were proposed.

Since it marked the trend of the times, the most interesting development during the nineties was the organization of the Oahu Sugar Company on the island of Oahu in 1896. This plantation was located, to a large extent, upon Campbell land and was dependent, initially, upon irrigation water pumped from wells similar to those which supplied its neighbor, the Ewa Plantation.

In view of lack of precise information as to the cost of pumping in Hawaii, promoters of the Ewa Plantation Company had leased only the low level lands of the Honouliuli ranch, the upper boundary being marked by the 200-foot contour. Prompted by the success of this company and encouraged by more reliable figures as to the costs involved, the Oahu Sugar Company, in addition to other lands, leased a strip above the Ewa Plantation extending to the 650-foot contour. That the economic pumping head for irrigation, if the entire supply is to be pumped, lies somewhere between these limits is evidenced by the fact that pumping by the Oahu Sugar Company has never extended to the upper edge of this strip.

Well boring for the new Oahu Sugar Company began immediately after organization and by 1897 was so far advanced that planting at a rate of 50 acres a day was possible (29). Fig 15 shows a low-lift, high capacity pump at Ewa Plantation Company.

These new successes on Oahu again prompted interest in pumping for irrigation. New plantations were begun on Lanai and Molokai with the idea of securing irrigation resources from an underground supply, while Waimea on Kauai, East Maui on the island of Maui, and Kohala on Hawaii sank wells to supplement the supply secured from stream diversion. The Honolulu Sugar Company and the Waialua Agricultural Company, both on Oahu, were organized at about the same time. Initially, the entire water resources for these plantations were secured from wells, although gravity water was soon secured as a supplemental supply.

The turn of the century introduced a period of high prosperity for those Hawaiian sugar plantations which had weathered the difficulties of the nineties. Annexation promised freedom from the constant threat of an exclusive tariff by the United States, while more settled labor conditions were hoped for at the time.

Consequently, the number of plantations increased, while many of those already operating increased their capital stock to finance expansion and betterments not previously justified. Although several of the newly formed plantations must have been irrigated from the beginning, no new principle seems to have been involved nor were the irrigation works developed for them of sufficient magnitude to justify mention in the public records of the period.

Fig. 14. Seed cane being irrigated by the long line method at Wailuku Sugar Company, Maui. The galvanized iron intake structures permit the careful control of the water. (Photograph by Wailuku Sugar Company.)

The promised prosperity of 1900 was reflected on the island of Maui by the construction of a new canal from East Maui by the Alexander and Baldwin interests in 1901. This canal, still called the Lowrie ditch, had its intake at the same point as the old Spreckels ditch, already mentioned, but due to better location and to the heavy construction involved delivered water at an elevation of about 450 feet above sea level at Spreckelsville. The original capacity of the ditch is reported as 60 M. G. D. The reported cost was $225,000. Since the right-of-way traversed lands of the Paia Sugar Company and the Haiku Sugar Company, rental in the form of one-tenth of the water conveyed was paid by the Hawaiian Commercial and Sugar Company to the two sugar companies involved. This water was subsequently divided between the Paia Sugar Company and the Haiku Sugar Company, eleven-twentieths of the amount going to the former and nine-twentieths to the latter. The writer of the contemporaneous account (19) again mentions the economic advantages of gravity diversion.

Major engineering construction was rapid in the first decade of the new century. The need for an additional water supply upon the Makaweli Plantation on Kauai was met by the construction of a 13-mile canal from the Olokele Valley by the Baldwin interests. M. M. O'Shaughnessy, later to be Chief Engineer for the city of San Francisco, was in charge of location and construction. This canal had a reported (30) capacity of 75 M. G. D. and cost $320,000.

The expansive spirit of the time was evidenced on Maui by the beginning of a 20 M. G. D. canal from Honokohau by the Pioneer Mill Company, and another great canal from the Koolau district on East Maui to serve the Hawaiian Commercial and Sugar Company, which had become an Alexander and Baldwin enterprise, and the Paia and Haiku Sugar companies. The Koolau ditcth, carrying 80 M. G. D., built under the direct supervision of O'Shaughnessy, was particularly remarkable in the great length of rock tunnel involved. About seven and a half miles, out of a total length of ten miles, are said (31) to be in tunnel section.

Fig. 15. A typical low-lift, high capacity pump at Ewa Plantation Company. This pump delivers 14 cubic feet per second from a shaft 43 feet deep. (Photograph by Ewa Plantation Company.)

An unique and economical method of developing water in Hawaii finds first printed mention in a short article on irrigation in the Territory by Mr. O'Shaughnessy, published in 1905 (13). This method, in common use at present, involves the driving of tunnels into lava formations at relatively high elevations, the seepage water and water released by the interception of lava tubes, which may carry relatively large flows, being led on a natural gradient to the tunnel portal and the point of use. O'Shaughnessy notes a recovery of 2 M. G. D. by a 500-foot tunnel at an elevation of 1400 feet at Waianae on Oahu. and 6 M. G. D. at Lahaina, Maui, from a tunnel 2600 feet long. In both these cases the author notes that the outward formation showed no sign of water resources. Experience, probably gained on the Olokele and Koolau ditches, prompted O'Shaughnessy to remark, however, that many long aqueducts, driven in territories as promising as those noted above, showed no sign of water interception. A short summary of the capital investment in irrigation work in the Territory up to 1905 is included in Mr. O'Shaughnessy's paper.

Waldeyer (23), in 1910, cited the necessary conditions for success with water development of this sort and listed the successful ventures between 1905 and 1910.

In the arduous and oftentimes dangerous work of tunneling the Japanese seem to have been particularly active. Yasutaro Soga (17) remarks upon the aptitude of the Japanese, particularly those from Fukuoka and Kamamoto prefectures, fot this sort of work in the *Nippu Jiji* for February 14, 1932. These men, due to native courage and resourcefulness, have contributed largely to the water resources of the Territory by hard rock tunneling. Particularly out-

standing is Nitaro Kawano, who in 1903 was responsible for the actual construction of the 24 tunnels on the Olokele project.

Additional water development for the Wailuku Sugar Co., which had resulted from the amalgamation of the three smaller companies on the eastern slopes of the West Maui mountains, was under way during the expansive period. This work involved the diversion of more water from the Iao Valley and its distribution over the fertile plains at the valley mouth.

Although Schuyler and Allardt (16) had called attention to the possibilities of gravity water storage near Wahiawa, Oahu, in 1889, no development was begun until about 1900. Seven years of effort in this area and the investment of $300,000 resulted in the completion of the Wahiawa dam in 1907. This dam, constructed by an independent water company, stored the drainage of 8000 acres and doubled the area of cane land irrigated by the Waialua Agricultural Company, to which organization most, if not all, the water is sold. A description by Thomas (20) gives the information that water from this reservoir was sold for one-third of a cent per hour for each miner's inch, or $6.17 per million gallons. Although no mention is made of which of the many miners' inches is intended, the equivalent value suggests the unit in common use in Southern California, where a miner's inch is taken as one-fiftieth of a cubic foot per second. This reference to the miner's inch as a unit of water measurement is the only one in which this inconvenient and highly artificial unit is encountered in the literature of water development in Hawaii.

One of the few cooperative ventures in water development in the Territory was begun at about the same time and promised additional water resources for the Wailuku Sugar Company and the Hawaiian Commercial and Sugar Company, on Maui. The interests of these two companies in the new Waihee

Fig. 16. The border method at Ewa Plantation Company. This system of applying water has resulted in phenomenal savings in the labor of irrigating. (Photograph by Covell, Honolulu.)

canal, completed in 1908, are reported (32) as being seven-twelfths for the Wailuku Sugar Company and five-tweflths for the H. C. and S. Company. The original construction involved more than 10 miles of ditch, 22 tunnels and a 3-foot steel siphon across the Iao Valley. The reported cost was $160,000. Modern use of this cooperative canal grants the use of day water to the Wailuku Sugar Company, while night water, stored in reservoirs near Wailuku, is available to the H. C. and S. Company.

Another outstanding development of the period was the construction of the Kekaha-Waimea canal of Kekaha Sugar Company, which tapped the Waimea River on Kauai. No diversion dam was required, in this work, the intake being through a rock tunnel which enters a deep pool in the bottom of the river at an elevation of 550 feet. Sixteen miles of canal and tunnel sections carry 45 M. G. D. to Waiawa gulch where the main canal ends. Surplus water is used for power development. The reported (32) cost was $275,000.

In the meantime developments and expansion at the Oahu Sugar Company had increased the demand for water to such an extent that the pumping lift, for some areas, had reached 550 feet. The desirability of a supplemental gravity supply was evident, but all near-by streams were small and intermittent and consequently inadequate for the purpose. The only available source of water seemed to be in the Waiahole, Waikane and Kahana streams on the windward or "rainy" side of the island of Oahu and separated from the Oahu Sugar Company lands by the main mountain ridge of the island. Many reports had been made, from time to time, upon the feasibility of such an ambitious under-

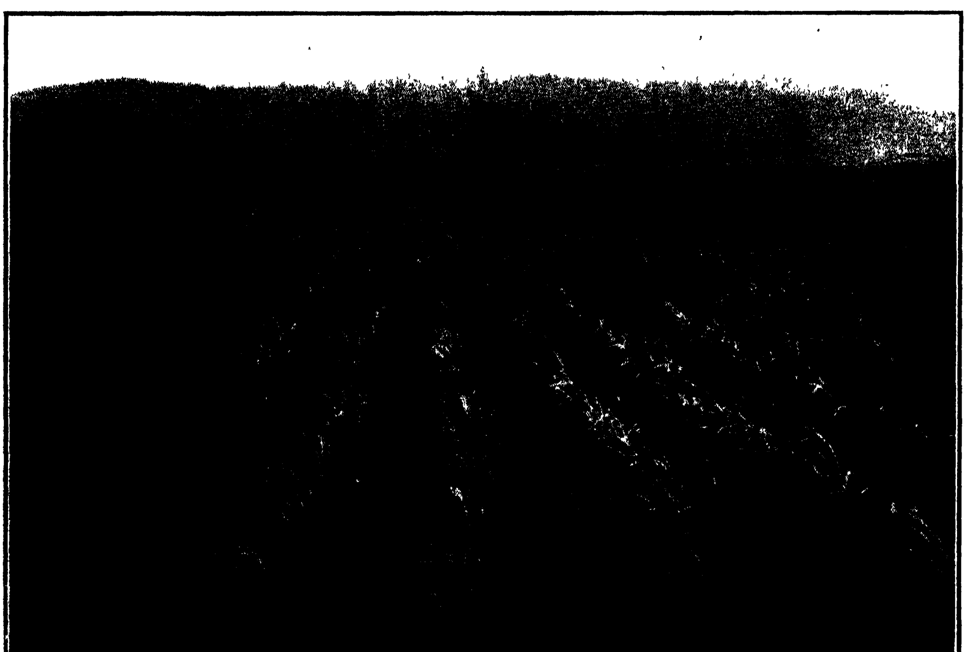

Fig. 17. Long line planting at Ewa Plantation Company. This method of planting and irrigating is useful on steeper slopes and more difficult topography than the border method. Great economies in labor have been effected by this system. (Photograph by Covell, Honolulu.)

taking by Mr. O'Shaughnessy, J. B. Lippencott, later to be chief engineer for the city of Los Angeles; J. Jorgensen, a local engineer, and others. The report of Mr. Lippencott (36) seems to have had greatest publicity and is quoted as having declared the scheme feasible but costly. The original estimate gave the probable cost as $1,500,000.

The need for water was great, however, and the Waiahole Water Company, organized in 1912, began work on the tremendous undertaking in February, 1913, in accordance with plans prepared by Mr. Lippencott. H. K. Bishop, appointed chief engineer at the beginning of the venture, resigned in October of the same year and was replaced by Mr. Jorgensen, who carried the work to a successful conclusion.

The construction of the main tunnel almost three miles long was marked with greatest difficulty. Mr. Jorgensen describes the construction in an unpublished report prepared for the Army in 1918. Here he says in part:

> Rain water had saturated the intervening porous lava rock with the result, that an easy outlet being afforded by the tunnel bore, a great flow of water was obtained when these dykes were penetrated. Dykes of this description were encountered from within 200 feet of the portal for a distance of about 4000 feet with intervals of various lengths of ordinary lava rock. At first the developed water was taken care of by ditching below the tunnel floor, but as the water increased after each dyke penetration, other methods had to be resorted to, the slope of the north tunnel being downwards. At a distance of 900 feet from the portal the flow had increased to 26 million gallons per 24 hours, and the men were working in water up to their waists, the drain ditch being unable to carry the water off, although 5 feet below the floor. The water poured from the top, sides, bottom and face with a pressure of 65 pounds per square inch in drill holes, necessitating impounding the explosives in tin cylinders and anchoring the charges in the holes. A sump was finally made close to the face and a 16-inch wood stave pipe installed as a siphon, which was later augmented by another 20-inch siphon placed on top of the 16-inch one. New sumps were made as the work progressed. At 1400 feet from the portal the water had increased to 36 million gallons per 24 hours and the siphons were unable to carry off the water, and it was finally decided to excavate a tunnel on the side of and a few feet above but parallel to the main tunnel and on an up-grade, with short lateral tunnels extending over the roof of the main tunnel. As the main flow of water came from above it was calculated that this tunnel and its laterals in this way would catch most of the water, and by driving the two tunnels simultaneously, make it possible for the men to work. This plan succeeded for a distance of 300 feet, when it was found necessary to excavate a sump in the main tunnel, install a centrifugal pump of 13 mil. gal. capacity and pump this amount of water to the upper tunnel, which at this time was 18′ above and 25′ on one side of the main tunnel. By this means slow progress was made till the south bore was met at a distance of 3200 feet from the north portal. At the south portal rapid progress was made after the installation of the proper machinery and electric storage battery locomotives were in service for hauling muck-cars. No effort was spared to get speed in this heading and the average progress maintained for a long time was 21 feet per 24 hours, as high as 684 feet in one month was obtained.

Fig. 18. A great siphon on the Waiahole Ditch. Such siphons as this cross the gulches between the tunnel portal and the agricultural lands of the Oahu Sugar Company. (An unidentified photograph in the files of the Experiment Station, H. S. P. A.)

Mr. Jorgensen's estimate of final cost is $2,000,000, not including the water rights which naturally had to be acquired.

A similar but much more dramatic account, containing a well deserved tribute to Mr. Jorgensen's engineering skill and resourcefulness, is to be found in *Thrum's Annual* for 1916 (33). Part of the heavy construction on the Waiahole ditch is shown in Fig. 18.

This expansive period was naturally marked with increased water demands on other plantations as well. Honolulu Plantation Company constructed a tunnel in Waimalu gulch as well as a small reservoir, while the Pioneer Mill Company began a new tunneling project similar to those reported by O'Shaughnessy (13). On Kauai plans were made to develop water in Wailua stream to supply homesteads in the vicinity and to augment the supply for the Lihue Plantation. By 1920 the Oahu Sugar Company had plans for additional pumping. Although the plantations on East Maui had long taken the lead in gravity water development, the convenience and flexibility of pumping had not been overlooked. In 1923 the Maui Agricultural Company, resulting from an amalgamation of the Haiku and Paia plantations, is reported (34) as having installed a steam-turbine-driven high lift displacement pump with a capacity of 12 M. G. D. The total lift of 751 feet is reported as being the greatest in the Territory.

The year 1924 saw the completion of the latest great gravity development in the Territory. The Wailoa ditch, built by the Hawaiian Commercial and Sugar Company and the Maui Agricultural Company, once more tapped the great water resources of East Maui. Diverting the waters of Nahiku stream, 30

Fig. 19. Kauhikoa Ditch. This canal from the great water resources of east Maui is typical of the heavy irrigation construction in that area. (Photograph from "The Kauhikoa Ditch," by Collins.)

miles away, the Wailoa canal supplies 145 M. G. D. through the largest canal in the islands. It is concrete-lined throughout. Emerging upon the Maui plains at an elevation of 1100 feet, it supplies gravity water to a large area previously supplied by pumps (35).

As has been noted, irrigation development has been largely affected by economic conditions, periods of high sugar prices being reflected in increased interest in water development. Naturally the low prices of the present result in curtailment of expansion. One large project, involving gravity water storage by a hydraulic fill dam for use on the McBryde Sugar Company, has recently been completed. This dam has drawn much favorable comment in the engineering world because of its advanced design.

It is well recognized that this brief history of the sequence of irrigation development in Hawaii cannot be complete. Behind the general pattern outlined above lie many minor schemes, some of which are too local to influence general trends, while others, such as the pumping ventures on Lanai and Molokai, seem to have been complete failures. Moreover, the consistent increase in the use of pumping units to supplement a gravity supply and the remarkable use of intercepting tunnels in one form or another found little mention in the records of the period after their novelty had worm off. At best this description of development outlines simple trends.

Plantation Utilization of Water

As has been indicated, little is known of the methods actually used for the distribution of water to the cane fields at Lahaina in the early days of irrigation. Presumably cane was planted in level lines and irrigated by admitting water from a ditch at one end. But there is no evidence as to how long these lines were. We do know, however, that the irrigators at Pioneer Mill Company worked in teams of two. One of these men turned the water into each line while his teammate waited for its appearance at the far end. When the line was full, this observer called "piha," or full, and the water was turned into the next line. The operation was then repeated.

C. A. Buchanan, for many years associated with the Pioneer Mill Company, tells that this practice continued until operations of this sort took place for an entire night under Mr. Campbell's bedroom window. Lack of sleep resulting from the frequent calls of the irrigator's assistant prompted an investigation in the morning; as a result, the irrigator lost his helper. Many years passed before a further labor reduction of 50 per cent was possible in irrigation.

How the method used at Lahaina differed from those adopted at Wailuku as a result of Willfong's "experiment," which has been mentioned, is not known. Nor do we know how either of these differed from the method of level lines introduced to Grove Farm by G. N. Wilcox and subsequently adopted by the Kauai plantations.

It is clear, however, that the common method used by most, if not all, irrigated plantations at the beginning of the century, involved planting cane in furrows about five feet apart, these furrows being so located that each followed a contour

line. In general, water was supplied to the lines by "watercourses" drawn at right angles to the contours and consequently at right angles to the cane rows. These watercourses were about 35 feet apart and secured their supply of water from larger ditches, which crossed the fields on flat grades at intervals of 200 to 300 feet. The success of this method, which proved its worth through many years of service, provides a commentary on the properties of Hawaiian soils. Few mainland soils could withstand the erosive effect of water on the steep grades used in the watercourses under local practice.

Desirable as the standard contour line may have been, attempts were made to better it, either by modifying the general scheme toward the end of reducing the labor involved, or reducing the amount of water used at each application. In some cases still another improvement was sought, that being an increase in the flexibility of operation so that freshet water might be expeditiously but perhaps unevenly applied during its few hours of availability.

Naturally in view of the different ends desired by different plantations, many modifications were suggested and tried, often with considerable success. Alexander (2) describes many of them.

Except for one or two of these modifications of the contour line method, which are of greatest value in the handling of freshet flows, all these schemes involved trapping water in a closed level furrow and allowing that water to seep into the soil without respect to the time required.

Another chapter in the story of improvements in irrigation practice begins with the use of methods involving the introduction of water at the top of a slope and letting seepage into the soil take place only while water is flowing over it. Although of long usage in Continental United States, the first use of this general principle in Hawaii is reported as beginning in 1921 (2). Here the cane was planted in lines on the usual spacing. But in place of running with the contours, these lines ran at right angles to them. Water introduced into the upper end of the lines naturally flowed down the lines under the influence of the slope, irrigating the plants as it reached them. When the water was turned out of the line seepage stopped, excess water flowing out of the line into the next supply ditch.

Apparently the general scheme was conceived independently as far as local practice is concerned, and almost concurrently at Ewa Plantation Company on Oahu and at Kilauea Sugar Plantation Company on Kauai. At Ewa the method called the "No Watercourse System" for obvious reasons was not particularly successful, at least no large area was irrigated by this means. But at Kilauea, under the guidance of L. D. Larsen, at that time manager of the plantation, the system soon proved its worth and had become one of the methods in common use by 1932. Details of labor and water economies effected by this method are to be found in the annual reports of the Hawaiian Sugar Planters' Association for 1931 and 1932. Two examples of long line planting are given in Figs. 14 and 17.

In the meantime the conditions at Ewa had directed attention in quite a different direction. Since some of the fields on this plantation are extremely flat, great difficulty was experienced in keeping water in the watercourses during the irrigation. Despite every possible care, water escaped from this ditch, and the situation became worse as the cane grew, increasing the resistance to flow and requir-

ing a greater head in the watercourse. About 1925, a new policy was adopted for such fields. Large areas were enclosed within substantial levees and the enclosed area flooded in much the same manner as rice or taro, except, of course, that no long-continued submergence was permitted. The yields of these fields were surprisingly good as measured either by cane or sugar, and although it may have been wasteful with respect to water used, it was markedly economical of labor (Fig. 11).

Naturally, this method of flooding was only suitable for flat fields, but the success gained in such areas prompted an enthusiastic trial of the border method so long used in the irrigation of alfalfa and field crops in the irrigated West.

This method involves enclosing long narrow strips of land which run down a slight but significant grade. These strips or borders, as they are almost universally called, are level from side to side and, in normal Hawaiian practice, carry four rows of cane, these rows being parallel to the long axis of the border. Water admitted to the top of the border spreads from side to side since the border is level in that direction and moves down the border in a thin sheet under the influence of the slope. At Ewa, this method has been highly successful, amazing labor economies having been effected. Fig. 16 shows a border being irrigated. Frequent descriptive accounts of the procedure, as well as cost figures, have appeared since 1928 in *The Hawaiian Planters' Record*, the *Reports of the Association of Hawaiian Sugar Technologists*, and in papers prepared for presentation at the annual meetings of the Hawaiian Sugar Planters' Association.

An ever-increasing appreciation of the value of irrigation water has been responsible for many forms of ditch linings. Some linings, particularly those in large canals of continuous flow, are of monolithic concrete, while other ditches are of hand-faced stone cut from local rock and set in cement mortar. In general the availability of suitable stone and the semi-skilled labor required has been a large factor in determining the type of lining used. Typical ditch sections before and after lining are illustrated in Figs. 12 and 13.

The lining of the smaller field ditches presents a more difficult problem and one which has been attacked in many ways. At McBryde Sugar Company pre-cast concrete slabs have been used, while at Hawaiian Commercial and Sugar Company a thin plaster lining of cement on poultry wire reënforcing is being tried once more after the previous failure of this method according to plantation tradition. Many forms of oil linings have been attempted with varying degrees of success. One method involving the use of a proprietary compound of asphalt has given some promise. The ideal ditch lining material for all conditions, if any exists, has apparently not been discovered. Developments within the next ten years should contribute materially to this field of irrigation improvement.

In the field of plantation improvement in irrigation practice, the perspective of the present does not lead to sound judgment of trends. A writer ten years hence may trace the development of these practices with much greater confidence due to the precise records of the present and to the wealth of descriptive material, which is now being made available.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD MARCH 21, 1933, TO JUNE 13, 1933

Date	Per Pound	Per Ton	Remarks
Mar. 21, 1933	3.025¢	$60.50	Puerto Ricos, 3.05; Cubas, 3.00.
" 22	2.98	59.60	Cubas.
" 27	2.95	59.00	Puerto Ricos, Philippines.
" 31	2.955	59.10	Puerto Ricos, 2.96; Philippines, 2.95
Apr. 4	2.99	59.80	Puerto Ricos, 2.98; Philippines, 3.00
" 6	3.05	61.00	Philippines.
" 10	3.00	60.00	Puerto Ricos.
" 13	3.05	61.00	Puerto Ricos.
" 17	3.10	62.00	Puerto Ricos.
" 18	3.11	62.20	Puerto Ricos, 3.10; Philippines, 3.12.
" 19	3.20	64.00	Puerto Ricos.
" 20	3.225	64.50	Puerto Ricos, 3.25; Philippines, Puerto Ricos, 3.20.
" 21	3.225	64.50	Cubas, 3.20; Cubas, Puerto Ricos, 3.25.
" 22	3.30	66.00	Cubas.
" 26	3.25	65.00	Philippines.
" 27	3.22	64.40	Philippines.
" 28	3.20	64.00	Puerto Ricos.
" 29	3.375	67.50	Cubas.
May 1	3.30	66.00	Puerto Ricos, Philippines.
" 2	3.31	66.20	Puerto Ricos.
" 3	3.35	67.00	Puerto Ricos, Philippines.
" 4	3.40	68.00	Cubas.
" 5	3.35	67.00	Puerto Ricos.
" 8	3.31	66.20	Puerto Ricos.
" 11	3.30	66.00	Puerto Ricos.
" 18	3.27	65.40	Puerto Ricos.
" 24	3.30	66.00	Philippines.
" 29	3.35	67.00	Puerto Ricos.
" 31	3.30	66.00	Puerto Ricos.
June 6	3.50	70.00	Philippines, Puerto Ricos.
" 7	3.48	69.60	Puerto Ricos, St. Croix, 3.50; Philippines, 3.46.
" 9	3.46	69.20	Cubas.
" 12	3.40	68.00	Cubas.
" 13	3.35	67.00	Puerto Ricos.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVII FOURTH QUARTER, 1933 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Research and Government Economy:

We reproduce a statement on the importance of research in relation to government economy, as presented on the floor of Congress in Washington.

Biology of an Important Armyworm Parasite:

The nutgrass armyworm has been uncommon during the past year and a half The habits of the latest parasite in Hawaii of this armyworm are described, and its method of attack illustrated from life, together with drawings of some of the developmental stages of this imporant enemy of one of our conspicuous cane pests.

Measuring Temperatures in Terms of Day-Degrees:

The paper shows how to calculate accumulated day-degrees for any crop year from the data on temperature and areas under cultivation. The basic assumptions underlying the methods are also discussed briefly.

A Basic Fertilizer Plan and Schedule:

With the increased interest in differential fertilization for fields and parts of fields, a basic fertilizer plan and schedule is suggested, together with guides for deviating from same. The actual figures offered with this plan are approximations: suggestive rather than absolute, and they should thus be interpreted and used.

Phosphate Fixation in Hawaiian Soils:

A resumé is given of the researches by staff members upon the subject of Phosphate Fixation in Hawaiian Soils. A discussion is offered bearing upon the apparent association of soil colloids with the phenomenon of fixation. Examples are cited of a few common colloidal substances. A detailed account of a greenhouse experiment is described in which cane was successfully grown with insoluble phosphates. Practical suggestions are offered as a means of minimizing or bypassing the fixation by the soil of applied phosphate fertilizer.

The rate of fixation is considered particularly in reference to the period of time elapsing before complete fixation takes place and during which period the plant roots may have opportunity to absorb adequate quantities of phosphatic nutrient.

A discussion is offered bearing upon the matter of equilibrium between the phosphate in the fixed reserve and that residing in the soil solution. Other topics referred to embrace the relationships of base exchange to fixation, the employment of fertilizer briquettes, the marked contrast of the degree of fixation in surface and subsoils, the geographic variability of the phenomenon, and the importance of employing a form of phosphate fertilizer most appropriate to the soil conditions in which the crop will be grown.

Variation of Mineral Content of Sugar Cane with Age and Seasons:

Results and discussion are given relative to an investigation of changes which occur in the mineral composition of the sugar cane plant with age and season. Monthly examination was made of various parts of the plant between the ages of one and twenty-four months. Figures illustrating the observed changes are presented.

Water:

We would commend for careful reading the address delivered before the Hawaiian Academy of Science by its retiring President, C. S. Judd. In this address the speaker, in clear and convincing statements cast in a pleasing style, tells the story of water; the material which made possible the origin and continuation of life on the earth and the development of man and his agriculture and arts. He calls attention to the numerous losses which civilization sustains through floods and erosion and argues for watershed protection to conserve water, land and the fertility of the soil.

In criticizing the Hoyt and Troxell report, the obvious purpose of which is to prove that "forests do not conserve the water supply," Mr. Judd displays charity and restraint when he uses no stronger language than "the lamentable inadequacy of the report," "the report presents an amazingly unbalanced picture of the many sided water problem," and "the lack of adequate analysis and evaluation of the several factors that account for relatively small increase of summer flow invalidates both conclusions and deductions of their report."

In their report, Hoyt and Troxell carefully avoid consideration of one factor which was in large part responsible for the results obtained. Consideration of this factor lies in the field of the engineer rather than in that of the forester—and the authors are engineers. One of the most obvious and best-known features attributable to a forest cover as a restrainer of surface run-off is the penetration of the soil by plant roots which open up avenues along which water may pass from the surface into underground channels. The cutting off of a forest may remove the vegetation above the surface of the ground, but it leaves the roots in the ground with their attending channels in the soil. These channels continue to function after the trees have disappeared and for many years the slow decay of the roots constantly improves their water-conducting capacity.

In the so-called "Wagon-Wheel-Gap Experiment," the forest cover was removed, thus adding to run-off the water formerly consumed by the trees and, at the same time, retaining on the watershed one of the most effective features created by the forest for the diversion of water from the surface into underground channels.

Mayor Laguardia On Research*

The election of Major Laguardia as mayor of New York City gives interest to his record in support of scientific research. As a member of the seventy-second Congress, speaking on December 28, 1932, in opposition to eliminate an item of approximately $39,000 from the agricultural appropriation bill, he said in part:

"Mr. Chairman: Science knows no politics. Are we in this frenzy of economy, brought about by those who control the wealth of this country, seeking to put a barrier on science and research for the paltry sum of $39,113 out of an appropriation of $100,000,000? Science will go on when existing political parties will long have been forgotten.

"I am sorry that the distinguished leader of the Republican Party in the House states that he is not versed in botany and publicly admits that he does not know anything of these terms or what it is all about; but, Mr. Chairman, it is indeed a sad day for the people of this country when we must close the doors of the laboratories doing research work for the people of the United States. The gentleman from New York says it is all foolish.

"Yes; it was foolish when Burbank was experimenting with wild cactus. It was foolish when the Wright boys went down to Kitty Hawk and had a contraption there that they were going to fly like birds. It was foolish when Robert Fulton tried to put a boiler into a sail boat and steam it up the Hudson. It was foolish when one of my ancestors thought the world was round and discovered this country that the gentleman from New York could become a Congressman. (Laughter.) . . . Do not seek to stop progress; do not seek to put the hand of politics on these scientific men who are doing a great work. As the gentleman from Texas points out, it is not the discharge of these particular employees that is at stake, it is all the work of investigation, of research, of experimentation that has been going on for years that will be stopped and lost."

The next day, when another item in the same bill was under consideration and the point was made that research in agriculture might well be curtailed because of current overproduction, Major LaGuardia said further:

"I want to say to my colleague, the gentleman from New York, that I believe he is confusing the purpose of experimentation and research work of this kind with the immediate question of production. Surely we can not delay scientific research until the time comes when this country will need greater production. That indeed would be lack of vision. The very purpose of this kind of investigation and study is to have the information complete and ready when it is wanted, for it can not be developed overnight. . . . .

"Momentary overproduction is not the important question. The important question is the continuing of study to correct the defects of nature. The most fascinating part of human activity is its constant combat with nature in fighting the elements and in correcting the defects of nature. This has engaged the attention of mankind from the earliest times of which we have record. Assuming, if you please, that we now have overproduction and production of more commodities than the people of the country have ability to purchase, that is no justification for closing the doors of these laboratories, closing the doors to scientific research and stopping it. We must continue it. The population is constantly increasing. Some day the legislative branch of government will keep abreast of science. Why, Mr. Chairman, the most humble research scientist in the Department of Agriculture is at this time contributing more to his country than the most useful Member of Congress. The most humble engineer in the General Electric Laboratory or the Radio Corporation of America Laboratory is more useful to humanity than the most brilliant orator of this House. The trouble is that the legislative branch of government has not kept abreast with science. Government has lagged, science has advanced. We have permitted an unbalanced system of distribution to continue while science has increased

* *Science*, Vol. LXXVIII, pp. 509-10, 1933.

production. We are living in the paradoxical state where there is great overproduction on the one hand and want and misery on the other. This is not the fault of science. This is the fault of government. This is the fault of men who have control of the governmental affairs of the country.

"I want to plead with my colleague, the gentleman from New York (Mr. Taber), in his eagerness—and he is sincere and works hard on these bills—not to be too hasty in cutting down these appropriations to continue this scientific work, so that when the time does come we will have the information available. I repeat, if the science of government had only advanced along with the progress made in electricity, chemistry, mechanics, transportation and agriculture, we should not today find ourselves in the midst of a ruinous financial crisis. While science and the arts and mechanics were progressing, government was struggling along with laws and economics founded on principles accepted centuries ago. Today we are still endeavoring to struggle along under construction and limitations of a constitution drafted and accepted at a time when steam had not yet been applied, before the railroads, before the telegraph, when electricity was entirely unknown, and in the days of hand production. Yes, gentlemen, science has forged ahead, and nothing that ignorance, petty politics, lack of vision, or hope to continue the old system may try to do can stop the onward march of science. So let not Congress seek to mitigate its shortcomings by attempting to adjust the universe with its own snail-like pace."

[H. L. L.]

Notes on the Biology of *Telenomus nawai* Ashm., An Important Parasite of the Armyworm *Spodoptera mauritia* (Boisd.)

By C. E. Pemberton

INTRODUCTION

During the last week of September, 1926, J. S. Rosa observed a minute black parasite on a cluster of eggs of the grass armyworm *Spodoptera mauritia* at the Experiment Station, H. S. P. A., in Honolulu. Suspecting this wasp to be an actual parasite of the eggs of the moth and possibly new to Hawaii, he saved the egg-cluster and on October 4, the following week, a number of identical parasites hatched from the eggs. His surmise proved correct, for upon examination O. H. Swezey found the parasite to be a species of Telenomus, a Scelionid not previously known in Hawaii (1), and subsequent study by A. B. Gahan, of the U. S. Bureau of Entomology, of specimens sent him by Mr. Swezey, revealed that the wasp was *Telenomus nawai* Ashm. (2). This parasite was first discovered by Y. Nawa in Gifu, Japan, in 1904, where it was found developing in eggs of an unknown moth. It was named and described the same year (3).

Following Mr. Rosa's discovery of the parasite, various entomologists of the Experiment Station staff soon found it parasitizing Spodoptera eggs in many parts of Honolulu. Mr. Rosa began breeding it for distribution to all of the islands in October, 1926, and by May, 1928, about 275,000 were reared and distributed. In March, 1928, Mr. Swezey found it established on Kauai. In April. 1929, Dr. F. X. Williams recovered specimens at Pioneer Mill Company, Maui. During March, 1930, Mr. Swezey found it on Molokai and in October, 1931, Dr

Williams found it parasitizing the moth eggs at Hutchinson Sugar Plantation Company on Hawaii. It has since been abundantly found at many locations and is thus well established on all of the main islands of the group.

This important armyworm parasite reached the islands accidentally and was not intentionally introduced, nor was it known to be of importance in Japan before it demonstrated its value here after becoming established. We can only conjecture as to how it reached Hawaii. It must have emerged from some moth eggs from Japan or the South Pacific after those eggs had reached Hawaii, but to our knowledge no new moth pest arrived with them. These eggs could have been on ornamental plants commonly carried on many ships stopping at Honolulu, or the parasites could have emerged from moth eggs plastered on a ship's woodwork or on packing cases discharged in Honolulu, or in many other situations, since many moths are not particular where they place their eggs. As this parasite has been reared from the eggs of another moth (*Prodenia litura* Fabr.) by H. W. Simmonds (4), at Levuka, Fiji (1925), it may very possibly have reached Hawaii from the Fiji group rather than Japan.

To date, *Telenomus nawai* has been found to parasitize only the eggs of our so-called nutgrass armyworm *Spodoptera mauritia*. Mr. Swezey (5) attempted to rear it on the eggs of various Lepidoptera but succeeded only when using *Spodoptera mauritia* eggs.

During March, April and May, 1933, the writer had opportunity to make some studies of the biology of this parasite. The salient features of its life habits are given below. Mr. Rosa has added much to our knowledge of the parasite. During the two and one-half years of breeding it for distribution to plantations he compiled some interesting notes. These are included.

Oviposition

The female parasite begins ovipositing in moth eggs almost immediately after hatching if eggs can be found. Freshly laid eggs are preferred. W. Twigg-Smith has obtained some excellent magnified photographs from life of a number of these parasites in the act of stinging a mass of Spodoptera eggs and laying their own eggs within them, as shown in Fig. 1. The parasite requires but a few seconds to force its ovipositor into a moth egg. It then remains almost motionless usually for 40 or 50 seconds, during which time its own egg is passed from its body down through the ovipositor and into the interior of the host egg. The ovipositor is then quickly withdrawn and cleaned for about 5 to 30 seconds between the hind tarsi or feet. The parasite then immediately moves to the next or nearby egg and repeats the operation. One parasite was kept under observation when ovipositing over an egg mass on April 30, 1933, for one and one-half hours. During this time, 62 moth eggs were stung and apparently parasitized before the parasite crawled off of the egg mass and ceased operations. This is the usual procedure. Sometimes fewer eggs are laid at any given period before the parasite stops to rest and sometimes more. The moth eggs are often laid in layers two or three tiers thick. In such cases the parasite has no difficulty forcing its small body or narrow abdomen down between the layers to reach the eggs at the bottom.

Occasionally two parasites will be seen stinging and laying into the same moth egg. Dissection of this egg will usually show that two parasite eggs have been

deposited, but after further study it was found that only one parasite ultimately developed. Mr. Rosa has segregated many individual parasitized eggs into separate vials and never did more than one parasite ever issue from such eggs.

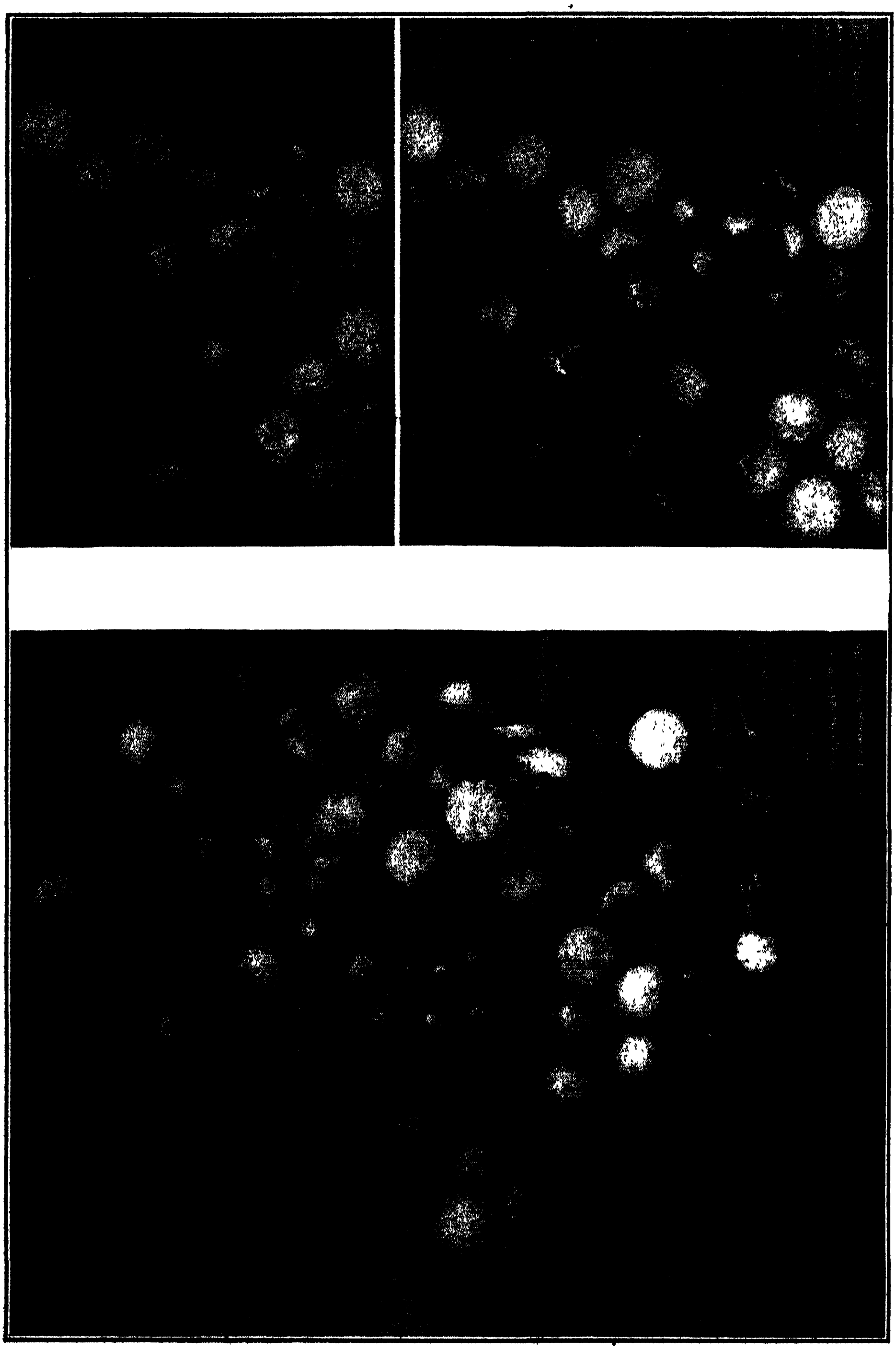

Fig. 1. Magnified photos from life showing *Telenomus nawai* females actually ovipositing in eggs of the armyworm *Spodoptera mauritia*.

Dissection of the ovaries of freshly hatched females usually show about 63 to 84 mature eggs present. Each parasite is thus capable of parasitizing at least that many moth eggs. Records on the total number of progery possible for 10 individual parasites which Mr. Rosa kept under observation during February and March, 1928, ranged from 16 to 132 per parasite with an average of 89. In each case the parasite laid all of its eggs during the first few days of its life and never after the seventh day. Parasites can, however, be kept alive indoors in glass tubes and fed honey and water for from 10 to 20 days if given no chance to attack Spodoptera eggs.

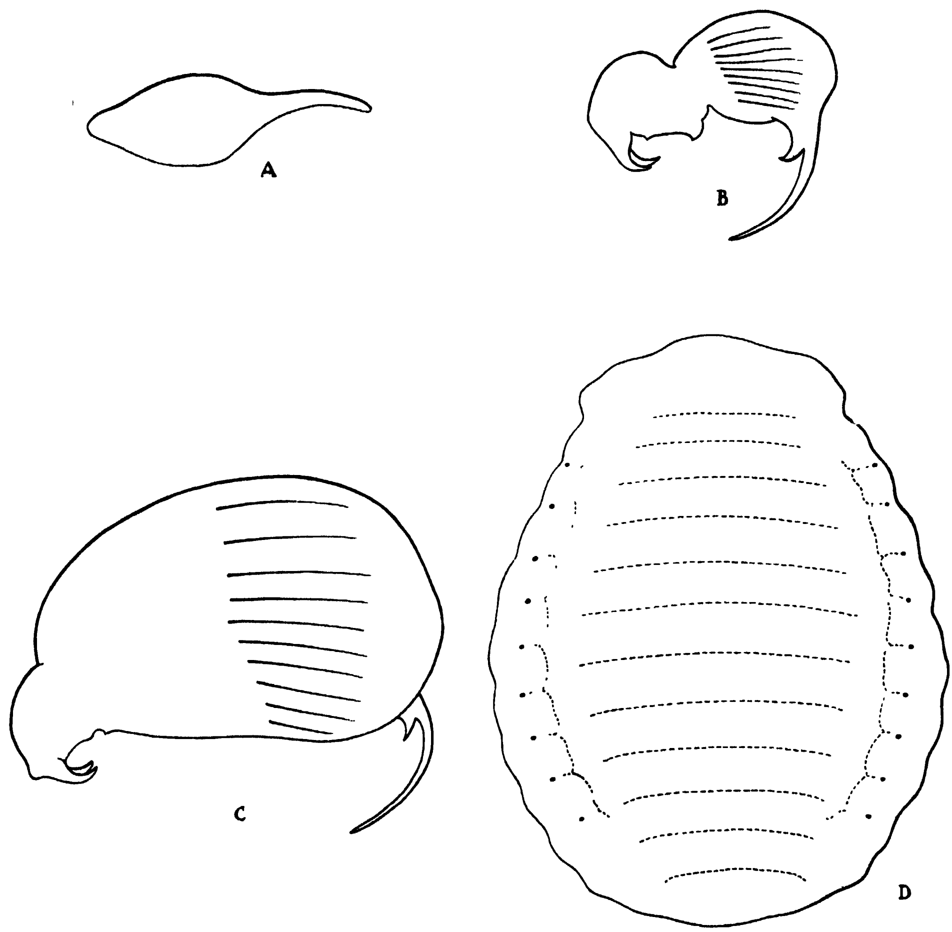

Fig. 2. Stages in the development of *Telenomus nawai* within Spodoptera eggs. Drawings to scale but greatly enlarged. A, newly deposited egg. B, newly hatched larva. C, engorged first stage larva 24 hours after hatching. D, appearance of larva about 36 hours after hatching.

The parasite is thus short-lived; but if moth eggs are available each parasite is capable in the few days of its active adult life of destroying about 50 to 80 of its host eggs and replacing them with an equal number of its own progeny.

The Egg

The freshly deposited egg of the parasite is .13 millimeter long or about one two-hundredths of an inch. It must necessarily be very small since it is placed

within the moth egg, which is only about one-fiftieth of an inch in diameter. It is shown in Fig. 2A. It is rather bullet-shaped with one end drawn out into a curved, blunt stalk. Within 24 hours after deposition it is slightly shorter, more oval in outline and the curved stalk at one end is much shortened and barely recognizable.

THE LARVA

Moth eggs, opened two days after being exposed to parasites, contain minute, strange-looking, legless, unsegmented larvae. One is shown in Fig. 2B. A tail-like appendage projects forward beneath the body which can be moved backwards and forwards. Elongate bristles, which can be also moved somewhat, extend backwards along the sides and over part of the top of the abdominal region. The head area bears a strong pair of curved mandibular processes. No tracheal or breathing system is discernible. The larva when first hatched is .11 millimeter long. About 24 hours later it has absorbed sufficient liquid food within the moth egg to have become greatly swollen and doubled in length, as shown in Fig. 2C. Otherwise its structure remains unchanged. Shortly thereafter it moults and assumes an entirely different appearance, as shown in Fig. 2D. It now has no distinct head or tail appendage. The body is smoothly oval. A weak constriction separates the head region from the rest of the body. Besides the head, twelve faint body segments can be recognized. A well-defined respiratory system has now developed with nine pairs of distinct lateral spiracles or breathing pores all connected with a tracheal trunk on each side. The larva is now .45 millimeter long. It has almost completely used up the contents of the moth egg and occupies most of its interior.

The larva pupates within the empty egg and from about 12 to 18 days after the parasite egg is first laid a newly matured wasp chews its way out and is soon ready to begin the cycle all over again.

THE ADULT

The parasite emerges from the moth egg through a ragged exit hole made by biting its way out. Moth eggs from which parasites have emerged are shown in the enlarged photo in Fig. 3, which was made by Mr. Twigg-Smith. Fig. 4 gives in detail the general appearance of the adult female greatly enlarged.

Males nearly always emerge first and remain on the Spodoptera egg mass awaiting the hatching of the females with which they immediately mate.

Females seem to outnumber the males slightly. During March, April and May, 1933, of a total of 2425 parasites hatching from moth eggs collected in the field on Oahu, 1386 were females, or 57.1 per cent.

LIFE CYCLE

The life cycle is very short. Life cycle data were kept in February, 1933, on 93 parasitized Spodoptera egg-masses, comprising a total of several thousand eggs. In all cases the period elapsing from the deposition of the parasite egg to the development and emergence of the adult ranged from 13 to 17 days with most of the emergence occurring in from 13 to 14 days. Life cycle data completed by

Mr. Rosa in March, 1928, on 894 parasites brought identical results. During the hot, summer months the cycle is a few days shorter. Mr. Swezey (6) found that the entire life cycle of the moth occupied from five to six weeks. The cycle of the moth is hence from two and one-half to three times as long as that of the parasite.

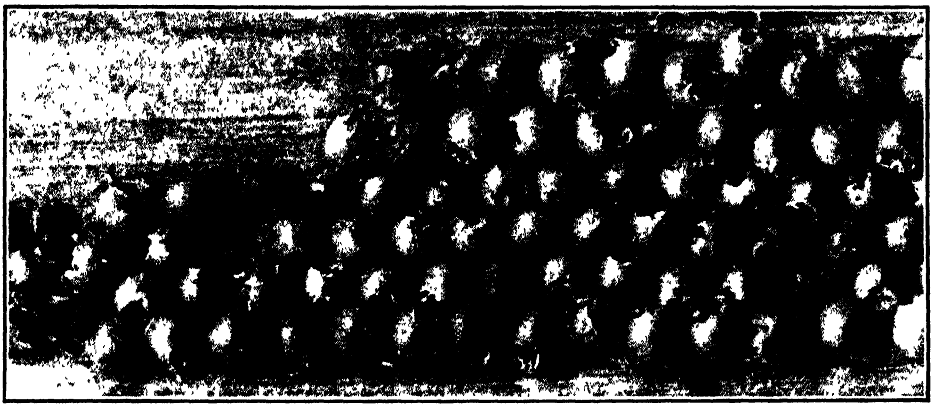

Fig. 3 Eggs of *Spodoptera mauritia* from which parasites have emerged, leaving a ragged exit hole over each empty egg shell. Greatly enlarged.

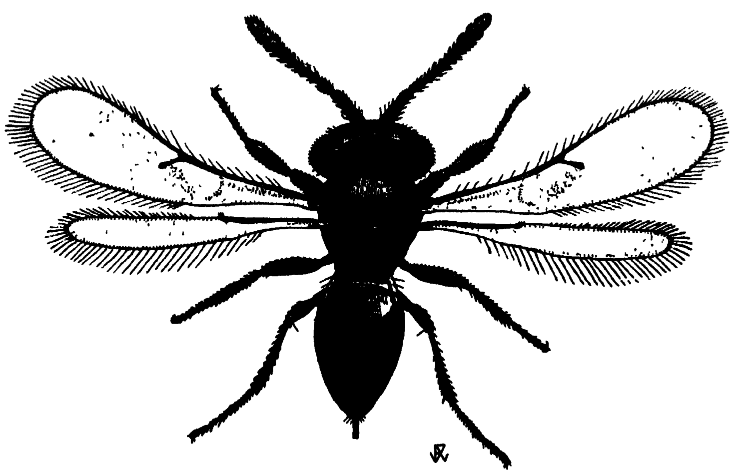

Fig. 4. *Telenomus nawai*, female, greatly enlarged. (After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*. 1931.)

Extent of Parasitism in the Field

When Spodoptera egg-masses are found by the parasite, nearly all of the eggs are quickly parasitized. As shown above, under Oviposition, a parasite will usually remain over an egg-mass for an hour or more and lay a large number of eggs once it locates a suitable egg-mass to attack. During May, 1933, 34 Spodoptera egg-masses were collected about Honolulu from cane leaves and at Mapulehu, Molokai, from date palm leaves. These were placed in individual vials to determine the extent of parasitism in each lot. The results give a fair

picture of the value of this parasite. From the 34 lots of egg-masses, 4914 of the eggs produced parasites and only 206 yielded armyworms. This is a parasitism of over 95 per cent. All of the egg-masses but six produced nothing but parasites. Moth eggs deposited on cane leaves and other plants about the Experiment Station grounds in Honolulu and in other parts of the city are usually highly parasitized. However, when the moth flies far afield into cane areas, the minute parasite is slow to follow or may fail to reach regions suddenly invaded by armyworms. The more frequent finding of it within cane fields in recent years is nevertheless encouraging.

During December, 1927, Mr. Rosa collected 38 Spodoptera egg-masses from cane leaves on the Experiment Station grounds and obtained the parasitism record for each lot. Of these, all but five produced nothing but parasites. A total of 5320 parasites and 74 armyworms hatched out. This is a parasitism of over 98 per cent and is again impressive proof of the ability of this parasite to destroy Spodoptera eggs when locating them.

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How to Measure Effective Temperature in Terms of Day-Degrees

By U. K. Das

The four essentials of crop production are:

(1) Plant food
(2) Moisture
(3) Heat
(4) Light

Of these four, we are accustomed to measure the quantity of plant food that we apply to the soil and the moisture that we receive in rainfall or that we supply by irrigation. We know that in general, our crop yields are markedly influenced by the quantity of both plant food and moisture.

Hereunder, we go a step further and suggest a similarly useful way of measuring the third essential of crop production, namely, heat or temperature.

The temperature as usually measured by thermometers does not tell us how much of it is effective for promoting growth. We know, for instance, that water

freezes at 32° F. and, therefore, there can be no growth at 32° F. It has been found with crops growing in cold countries, like Europe, that vegetation really begins to grow at about 42° F. In that case only temperatures above 42° F. would promote growth. But the fact that sugar cane does not grow very much outside of the tropics would suggest that profitable cane growth cannot take place at temperatures where subtropical crops would thrive. In other words, the heat requirements of cane must be greater. What may be the lowest point at which measurable cane growth will cease has not been experimentally determined. We therefore arrive at a probable value for this minimum point in an indirect manner.

In Louisiana, cane does not generally grow in winter when the mean maximum air temperature is about 63° F. (New Orleans station). Growth starts in early spring in March when the mean maximum temperature is 70° F. Local observations and meager data on hand would indicate that this zero point of cane growth in Hawaii also is in the neighborhood of 70° F.

We therefore assume that measurable cane growth starts at 70° F. of maximum temperature. That this assumed point is not so very far from the truth will be clear when we consider that with a summer temperature of 86° F. and a winter temperature of 78° F., we get nearly two to three times as much growth in summer as in winter. This can only be true if the starting point of cane growth is about 70°. (Very recent studies indicate that this point may be nearer to 73° F. than to 70° F., but until this point is definitely established, we would recommend the use of 70° F. as the zero point.

Accumulated Warmth or Effective Temperature

Effective temperature will then be measured from this base line of 70° F. of maximum temperature. One day having 71° F. of maximum temperature will then be one effective degree for one day or one day-degree.* If we have 30 such days in one month the total effective warmth will be 30 × 1 or 30 day-degrees. If, on the other hand, we have a day with 85° F. of maximum temperature, that day has 85°— 70° or 15 day-degrees of heat. If a month in summer, say, August, has a mean maximum temperature of 85° F. (which means that the average maximum temperature of each day is 85° F.), then, the total day-degrees for that month will be the sum of day-degrees in each of the 31 days, or, more conveniently, the day-degrees for an average day multiplied by 31. In this particular instance, this total will be 15 × 31 or 465 day-degrees. Thus, we see that we can add, subtract, multiply or use our temperature in any quantitative manner we want by resolving the temperature records into day-degrees. We can thus compare the sum total of day-degrees in one year with another and in one crop length with another. It is only when we come to evaluating the total warmth received by all the different fields of a plantation started and harvested in different months, that our simple method of summing up day-degrees fails to give us the true picture of the total effective heat received by the total crop. But this difficulty can easily be surmounted by taking into consideration the factors of area and crop length of different fields. Here we can apply the analogy of irrigation water or rainfall. If we give two inches of irrigation to an acre of land,

* Temperature below 70° F. is taken to be of zero value. Thus, days of 60° F., 65° F. or 69° F. all have zero day-degrees.

we say that the water received by the field is 2 acre inches. Two inches over 5 acres would be 10 acre inches and so on. We can do the same with day-degrees. If we have 15 day-degrees of heat received equally by all the fields of our plantation of 3,000 acres, then the total warmth for all the fields would naturally be 15 $\times$ 3,000 acre-day-degrees. Thus, we can calculate for every month the amount of heat received by multiplying the total day-degrees in the month by the area under cane in that month. The acre-day-degrees for each successive month of a crop can thus be added together to give us the total acre-day-degrees received by a particular crop. In Problem III, at the end of this paper, we show how to calculate this sum for a given crop.

In this manner not only can we compare this year's performance with another just as we would compare the efficiency of 200 pounds of N on our plantation this year with 300 pounds N next year, but also we shall be able to compare at any moment the progress to date of the current crop with the same date of the past crop. And this latter evaluation of crop progress to date is bound to be of great help in crop estimations.

Differences in Young and Old Cane

The calculations that we have suggested take no account of the fact that young cane grows faster than old cane and must, therefore, grow more for each day-degree of heat than old cane. Until such time as we have definite information on this difference of growth rate in young and old cane, we would suggest that we disregard this factor and content ourselves with knowing that the proportion of young and old cane in the different years must be approximately the same at any given period. Then, the comparative value of the summated day-degrees will still be good.

Data Must Be Reliable and Representative

Success in using these methods of evaluating warmth must primarily depend on (1) the reliability of the temperature records, (2) the representative character of the data. In other words, does the weather station truly represent conditions all over the plantations or is it of local significance only?

We would, therefore, suggest the use of approved Weather Bureau type of instruments only and we would also suggest that wherever necessary more than one temperature station should be established on the plantation.

Calculations

Problem I. To calculate the total acre-day-degrees for December, 1958.

Area under cultivation=2,000 acres.
Mean maximum temperature for December=80° F.

Therefore, total day-degrees for the month=(80—70)$\times$31=310.*
Total acre-day-degrees=310$\times$2,000=620,000.*

* It must be understood, however, that if we have many days in the month with temperatures below the base line of 70° F., then the short cut method of multiplying mean maximum temperature by the number of days in the month will not give us the true number of day-degrees. In such cases, the daily day degrees must be added together.

Problem II. To calculate effective warmth for the summer months, July. August, September, of 1958.

Data=

Area in cane, July =2,000 acres.
August =2,600 acres.
September=3,200 acres.

Temperature mean maximum July =85°.
August =86°.
September=87°.

Day-degree for July =(85—70)×31=465=0.465 thousands of day-degrees.
August =(86—70)×31=496=0.496 thousands of day-degrees.
September=(87—80)×30=510=0.510 thousands of day-degrees.

Thousands of acre-day-degrees for July =0.465×2000= 930.0.
August =0.496×2600=1289.6.
September=0.510×3200=1632.0.

Total for three months = 3,851.6.

Problem III. To calculate the total acre-day-degrees for the crop of 1935 of plantation X, the following table shows the data and the calculations:

A Month	B Area in Cane for 1935 Crop (Acres)	C Mean Max. Temp. for the Months	D Effective Heat for One Day (t°—70°)	Day-degrees for the Month. (No. of Days × Effective Heat)	F Thousands of Day-deg. (Day Degrees÷1000)	G Thousands of Acre-Day-degrees F.×Area	H Accumulated Thousands of Acre Day-deg. to Date
1933							
J	300	78	8	248	0.248	74.4	.....
F	600	79	9	252	0.252	151.2	225.6
M	900	80	10	310	0.310	279.0	504.6
A	1200	81	11	330	0.330	396.0	900.6
M	1500	82	12	372	0.372	558.0	1458.6
J	1800	83	13	390	0.390	802.0	2260.6
J	2100	84	14	434	0.434	911.4	3172.0
A	2400	85	15	465	0.465	1116.0	4288.0
S	2700	84	14	420	0.420	1134.0	5422.0
O	"	83	13	403	0.403	1088.1	6510.1
N	"	82	12	360	0.360	972.0	7482.1
D	"	81	11	341	0.341	921.0	8403.1
1934							
J	"	79	9	279	0.279	753.3	9156.4
F	"	80	10	280	etc.	756.0	9912.4
M	"	81	11	341		920.7	10833.1
A	"	82	12	360		972.0	11805.1
M	"	83	13	403		1088.1	12893.2
J	"	84	14	420		1134.0	14027.0
J	"	85	15	465		1255.5	15282.7
A	"	86	16	496		1339.2	16621.9
S	"	85	15	450		1215.0	17836.9
O	"	84	14	434		1171.8	19008.7
N	"	83	13	390		1053.0	20061.7
D	"	82	12	372		1004.4	21066.1
1935							
J	"	77	7	217		785.9	21852.0
F	2400	78	8	224		537.6	22389.6
M	2100	79	9	279		585.9	22975.5
A	1800	80	10	300		540.0	23515.5
M	1500	81	11	401		601.5	24117.0
J	1200	82	12	360		432.0	24549.0
J	900	83	13	403		362.7	24911.7
A	600	84	14	434		260.4	25172.1
S	300	85	15	450		135.0	25307.1
		Total				25307.1	

NOTE—All data are imaginary. Assumed nine months of harvest from January to September.

Use of Day-Degree to Compare One Area With Another

The day-degree may also be advantageously used to compare the performance of one field or area with another. In that case we can measure the yields of the two areas in terms of "yield per acre per 1,000 day-degrees." Thus, we may find that there is no difference between a mauka and makai land yielding, say, 5 and 7 tons, respectively, of sugar when we reduce this yield to the basis of 1,000 day-degrees.

A Basic Fertilizer Plan and Schedule

By R. J. Borden

With the premise that it is necessary for us to use commercial nitrogen, phosphoric acid, and potash fertilizers, if we are to continuously produce economical crops of sugar cane, we are immediately concerned with a plan that will make use of these nutrients in a way that will be reflected in enhanced profits. With a further premise that any one of these nutrients may be safely omitted from a fertilizer practice only when we have evidence that the natural supply within the root zone will be sufficient for the immediate crop, and that supplementary additions to a satisfied soil would only result in an intensified absorption without an increase in yield, we are then interested in finding such evidence. Fortunately, the chemist, the plant physiologist, and the agriculturist have cooperated to give us guides to intelligent fertilization that are extremely useful. though not always infallible, and as we make wider use of such guides and become more adept in interpreting their results, our use of fertilizers will become more efficient and profitable.

Amount to Apply

Without evidence to the contrary, a conservative fertilizer practice that recognizes the necessity for preserving the soil as well as for providing the necessary chemical foods for the cane plant to convert into sugar, might well be built out in two directions from a base line that would supply each crop with 200 pounds each of nitrogen, phosphoric acid, and potash. Departures from this base line would be made as evidence became available to indicate that more or less of any one nutrient was desirable. Such a basic fertilizer, at present prices for commercial materials, should not cost much over $35 per acre applied in the field, ($15 for nitrogen, and $10 each for phosphate and potash), and hence appears a very reasonable expenditure for the increased sugar yield it is capable of making. With such information as the expected cane tonnage, the results of chemical analyses of soils, soil solutions and leachates, and of the cane plant tissues and juices, and of the by-products of manufactured sugar, as well as the results from Aspergillus and from Mitscherlich tests with indicator crops, and of the field experiments with sugar cane itself, we have guides for deviating from this basic plan that will help us to increase its efficiency or to decrease its cost. Hence the

following plan is offered, with the suggestion that all quantitative data therein be considered not as absolute amounts but as rough estimates of trends or directions for guidance.

A BASIC FERTILIZER PLAN

With Guides for Deviating From Same

Lbs. to be applied	N	P_2O_5	K_2O
0		No response to P_2O_5 in field tests. Cit. sol. at .008% +. .04% + in juice. Mitsch. at 250 lbs. +.	No response to K_2O in field tests. Cit. sol. at .04% +. Mitsch. at 750 lbs. +. Molasses at 5.0%.
100		Cit. sol. at .004% +. .03% + in juice. Mitsch. at 150 lbs. +.	Cit. sol. at .03% +. Mitsch. at 550 lbs. +.
150	For 40-50 tons		
200	BASIC SCHEDULE For 60-70 Tons Cane		
250	For 80-90 tons Long crops		
300	For 100 tons Long crops	.01% in juice. Phosphates added to juices at the mill.	Cit. sol. at .01% —. Mitsch. at 250 lbs. —.

The Citric Soluble and Mitscherlich analyses are to be made on soil samples collected immediately after the harvest of the crop upon which juice analyses were made, and the information thus obtained is to be used as a guide for fertilizing the succeeding crop.

The amounts suggested in this roughly devised basic fertilizer plan have been conceived as sufficient for the average 60- to 70-ton cane crop. For lesser tonnages, the suggested amounts may be decreased from the 200-200-200 base line, although it is doubtful whether the nitrogen figure should be planned at much less than 125 to 150 pounds. For greater tonnages, increases over the base application, particularly of nitrogen, are in order.

As regards phosphoric acid: If it is a practice to add phosphates at the mill in order to settle the cane juices, or if an analysis of the crusher juice shows a P_2O_5 content of less than .01 per cent, we have a fairly sure indication that the soil phosphate supply is pretty low and that a somewhat heavier crop fertilization with phosphate is called for. On the other hand, if a fairly good agreement exists on the other (upper) side of our base line for P_2O_5, between the figures that indicate a medium to high supply of this nutrient in the soil and in the plant, we may well consider decreasing the amount to be applied. In a case where the guides *all* point to a large available supply of phosphates, we believe that we can safely omit this material from the fertilizer practice. Whenever such a decision is made, however, it will be wise to install a good field experiment that will afford

a check on a series of yields of paired plots with and without phosphate. Such an experiment should be continued as long as our decision to withhold phosphate fertilizer is effective, so that we may catch a trend in the experiment before it becomes operative in the field.

With citric soluble K_2O in a soil at less than .01 per cent, or with a Mitscherlich figure indicating less than 250 pounds available to Sudan grass, we feel that an increase in potash over the basic application is warranted. Where, however, the evidence quite clearly points to an ample supply for the crop, we believe that a considerable cost saving can be made by decreasing or by even eliminating potash from the crop fertilizer program. Such a decision as the latter would concurrently be checked by field experiments in order to watch the trends that might follow such a procedure if continued for many years.

In using these suggested guides for deviating from the basic plan, one must be cautioned not to make decisions on the basis of any single guide alone. We have offered several and in time we should be able to offer still more. In the meantime, if there is a lack of agreement between the suggested guides in the same group, the wisest policy will be (1) to make sure that we are providing the cane plant with sufficient raw material to make the expected crop, and (2) to resample the field in question, since this lack of agreement may be due to inadequate or to non-representative sampling. Two hundred pounds of phosphate or of potash can be applied for about $10.00 per acre and unless we know quite definitely that the available soil supply is fully adequate, we cannot afford *not* to make this expenditure.

Time to Apply

After having decided on the amounts of nitrogen, phosphoric acid, and potash that we shall apply, we are later confronted with the problem of when these materials should be applied for greatest efficiency. We have many opinions, but little data to answer this question, but we believe that we have a good indication that is given to us by the cane plant itself.

With the use of soluble fertilizer salts which are readily available to the cane following their application to the soil, it would seem reasonable to try to supply the more elusive elements when and as needed by the plant. Thus the time and amount of absorption, particularly of N and K_2O by a healthy, well-nourished cane crop should offer a good guide to the time of application of these nutrients.

In the accompanying graphs there is presented a picture of the maximum amounts of N, P_2O_5, and K_2O that were found in an acre of cane (including roots, stalks, and leaves) at its various stages of growth. The data from which these graphs were drawn have been presented before* and the information is offered again as the best evidence we have for use in guiding our time of applying fertilizer. The two smaller graphs are interpolations from the larger graph to show the more rapid absorption of nutrients during the "boom stage" as contrasted with the slower but continued absorption during the same calendar months of the second year's growth. This is particularly true of potash and nitrogen.

* By G. R. Stewart at the 1929 meeting, and by W. W. G. Moir at the 1930 meeting of the Association of Hawaiian Sugar Technologists.

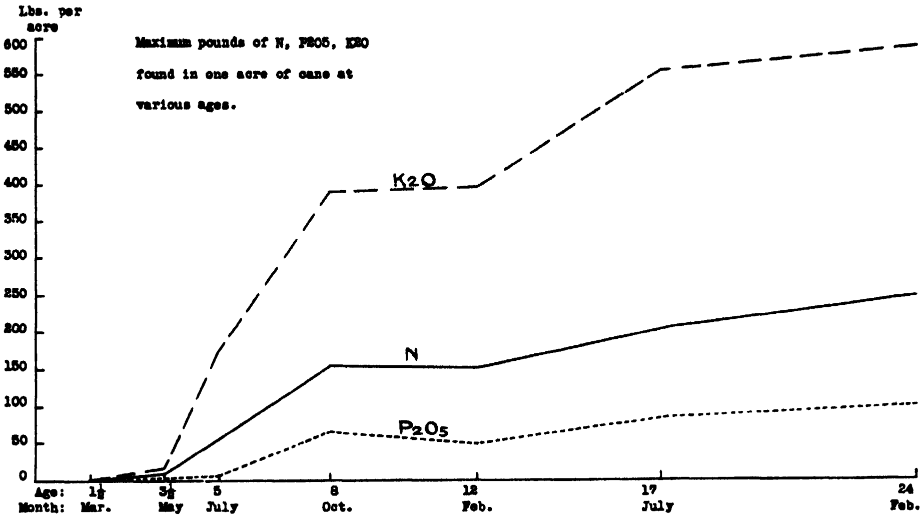

Lbs. per acre
600
550
500
450
400
350
300
250
200
150
100
50
0
Maximum pounds of N, P2O5, K2O
found in one acre of cane at
various ages.
K2O
N
P2O5
Age: 1½ 3½ 5 8 12 17 24
Month: Mar. May July Oct. Feb. July Feb.

Fig. 1

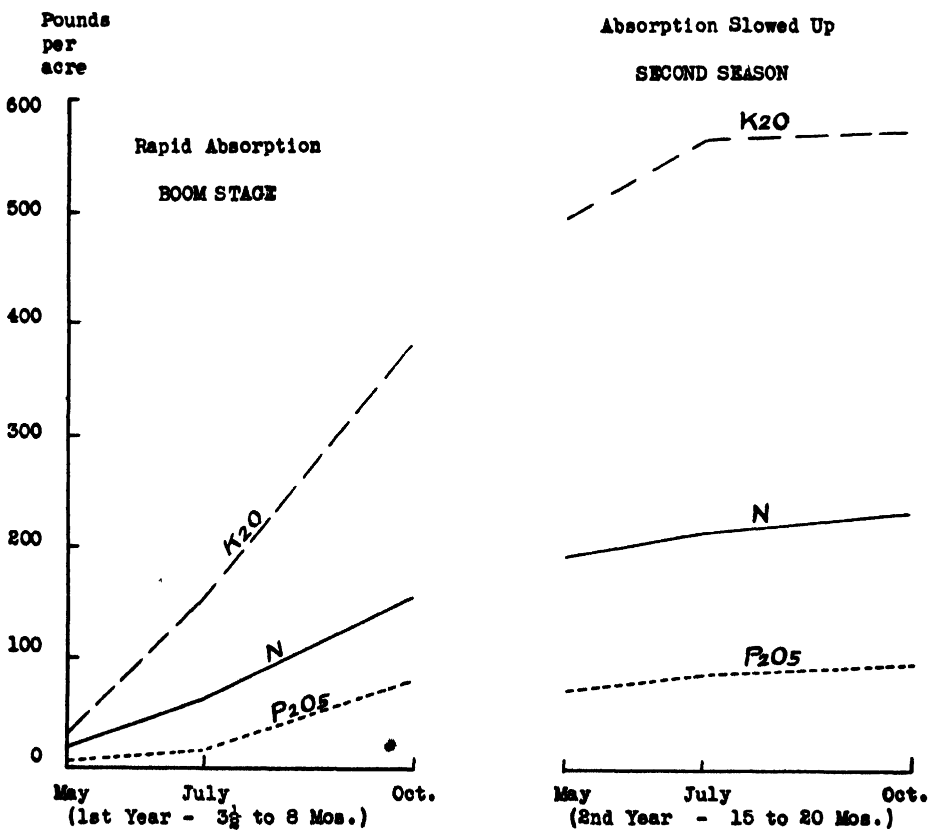

Pounds
per
acre
600
500
400
300
200
100
0
Rapid Absorption
BOOM STAGE
K2O
N
P2O5
May July Oct.
(1st Year - 3½ to 8 Mos.)
Absorption Slowed Up
SECOND SEASON
K2O
N
P2O5
May July Oct.
(2nd Year - 15 to 20 Mos.)

Fig. 2

An inspection of these graphs will show the following:

(1) Less than 10 per cent of the total N, P_2O_5, or K_2O which the cane finally had taken up at 24 months, was in the plant at the age of 3½ months.

(2) Less than 30 per cent of the total N, P_2O_5, or K_2O absorbed, had been taken up by the cane plant at 5 months.

(3) Only approximately 60 per cent of the total nutrients had been absorbed by the end of the twelfth month, and most of this absorption took place at from 3 to 9 months.

Considering the general nature and characteristics of our cane soils, and with these nutrient absorption data in front of us, we should like to offer the following schedule for applying the amounts of N, P_2O_5, and K_2O as indicated in our basic fertilizer:

(1) Not more than 10 per cent of the total nitrogen before the sixth week, with 20 to 30 per cent at 3 months, 30 to 40 per cent at 5 months, and the remainder after the eighth month, applied alongside the cane row.

(2) All the phosphate in a single application within the root zone as soon as the crop is started.

(3) Potash in a split application when the total amount is to be over 150 pounds per acre, preferably at about 3 and 5 months, applied alongside the cane row with the nitrogen.

Undoubtedly there will be many reasons for deviating from such a schedule as offered, and these will need to be considered in the light of their greater possible resultant values from the use of fertilizers to make profits from sugar production. Perhaps at some later date, such reasons will be evaluated and set down to guide us in making similar deviations from this basic schedule for time of application as we have already suggested for our basic amounts to apply.

Phosphate Fixation in Hawaiian Soils

By Francis E. Hance

The staff have devoted attention for some time to the study of the fixation of phosphates in Hawaiian soils.

The present paper is offered as a resumé of the developments brought about as a result of Experiment Station research.

An endeavor has been made to present the subject in terms of simplicity and to avoid the usual technical phraseology.

The term "fixation" in its general sense is defined as "the process of rendering permanent."

For our purposes phosphate fixation refers to the retention in the soil of applied soluble phosphate fertilizers by a process of absorption or chemical precipitation, or both. The process is not necessarily permanent. We believe it subject to correction, more or less.

Phosphates once fixed, however, may be held so tenaciously by the soil that root systems of plants can utilize or absorb but very small amounts. The requirements of the growing plant for phosphates are not uncommonly in excess of the supply

which the root systems may contact and absorb. Even a large application of a soluble phosphate such as ammophos or superphosphate may become locked up in the soil to such an extent that the plant may not be able to extract this applied phosphate fast enough to satisfy its needs. We say, then, that in such a case the application of phosphate fertilizer has been so tightly "fixed" as to seriously diminish the amount available to the plant.

In the investigation of phosphate fixation in any given soil it is necessary, of course, to add a quantity of known phosphate to that soil so that fixation may take place. If it were easy to remove all the phosphate which had been so applied and which had not become fixed, then it follows that analyses of the soil before and after fixation would show an increase in the amount of phosphate present. This amount would, of course, be equal to the quantity fixed. However, the method is very cumbersome. It is easier and equally as proper to analyze a solution before its application to the soil and again after it has passed through it under controlled circumstances. Then the decrease in the amount of phosphate in the solution can be used to calculate the amount of phosphate which has become fixed.

A soil extraction with a solution of phosphate is used with the Experiment Station phosphate fixation kit; likewise in employing the method of Demolon and Barbier and in other laboratory experimental work.

Results obtained by use of the phosphate fixation kit depend upon extraction of a soil with a neutral solution containing a definite concentration of phosphate. The soil is shaken with the solution and allowed to stand long enough for fixation to occur. Then the liquid is filtered off and certain chemicals are added to it which produce a blue color, the intensity of which is directly proportional to the phosphate remaining in solution. The lighter the color the less phosphate which has been fixed by the soil. Conversely, the darker the blue produced (within limits of the test) the more phosphate which is carried by the solution and hence not removed or fixed by the soil. The test serves as a means of ascertaining the relative fixing powers of various soils in a general way, and it can be used quickly and easily in the field or plantation laboratory.

It often happens that a particular strength of phosphate solution may produce in two soils the same apparent degree of fixation when measured by the standards of the fixation kit or by other simple methods. Hence, in evaluating such soils in respect to fixation characteristics, one may safely class them in the same general category. However, in a more detailed study of these two soils it may develop that any one or more of several strengths of phosphate solutions (differeing from the one referred to above) may react so differently when percolated in these soils that the similarity first generally indicated may be found actually as not as marked. For extensive researches it is accordingly advisable to extract a soil with a series of solutions containing different concentrations of phosphate. A more nearly complete understanding of the characteristics of a soil may be obtained in this manner.

We may digress a moment to suggest a field analogy. Consider the situation in the soil following an application by hand in the line of, say, 250 pounds per acre of P_2O_5 as ammophos. Let this be followed by a number of successive rains or irrigation. The first downward movement of water through this ammophos would carry a high concentration of the fertilizer. As the concentrated solution seeps

through the soil the latter may extract or fix a greater part of the phosphate which the solution carries. The actual zone of phosphate movement may not exceed 2 or 3 inches. Should this soil have very high "fixing" ability, the phosphate already fixed may be added to by additional phosphate dissolved in subsequent irrigation movements and, after an entire agricultural season, one may find that the maximum penetration of applied phosphate did not reach a level five inches below the surface. In another type of soil having mild "fixing" characteristics, the same amount of applied soluble fertilizer may reach the second or even third foot profile level. In most Hawaiian soils, however, fixation of applied soluble phosphates appears to occur over a variable period of time, well within the normal root zone areas and yet ultimately so completely that little or no loss of this nutrient is occasioned by seepage or leaching.

Relevant to methods of studying soils in reference to phosphate availability and soil phosphate fixation: We have seen that it is necessary to extract a soil with solutions of various reagents (including phosphate) in order to determine its probable behavior or reaction to fertilization in the field. A practice almost universally followed is to lightly acidify all solutions intended for laboratory soil extraction studies. Hence, in the evaluation of a soil for ascertaining its concentration of "available" or readily soluble nutrients an extraction is usually made with a dilute organic acid such as citric acid or a very dilute inorganic acid such as nitric acid or sulfuric acid. The acid extraction, within limitations, is designed to parallel the nutrient extracting ability of the plant roots. It has been found necessary in soil-phosphate fixation studies to employ dilute acid extractions together with solutions of phosphate-bearing salts. Related research requires soil and solution manipulations in which no acids are employed and in which field conditions pertaining to soil-fertilizer and irrigation are more nearly approximated. Regulated concentrations of phosphates in solution, however, are employed in all fixation studies.

Hence, in the method of Demolon and Barbier and in other researches in the laboratory, a series of extractions have been made using variable concentrations of phosphate in the process.

Demolon and Barbier, in their studies with French soils, used acetic acid extraction solutions containing variable amounts of phosphate. From the data certain calculations were made which enabled them to estimate the requirements of their soils.

Recently, Davis and Ayres have been using phosphate solutions containing no acids. This procedure has certain distinct advantages:

(1) The pH of the mixture is very nearly that present in a soil when phosphate fertilizers are added instead of being distinctly acid. Thus the results should more closely approximate what happens in the field.

(2) An acid dissolves an amount of the phosphate originally present in the soil at the time the sample is collected. This, added to the amount present in the solution constitutes the *true initial concentration* of the solution, part of which becomes fixed. But we do not know how much phosphate was dissolved since it does not all remain dissolved, but becomes partly fixed. With neutral solutions which do not dissolve phosphate appreciably in most cases, we know exactly how much has been added and how much remains soluble, and, therefore, how much has become fixed.

(3) Acid solutions change the characteristics of a soil very markedly and therefore introduce an additional complication.

(4) The analytical determination of phosphate in a neutral extract is much more simple and accurate than in an acid extract which contains iron and other interfering substances.

In making quantitative analytical studies of soil phosphate fixation the investigator must give full consideration to the mechanism of fixation as it occurs in the field.

It has been determined that phosphates do not become "fixed" by gravel or sand. It has also been established that phosphate must be soluble in water to become "fixed." It is also true that the presence of colloidal matter in a soil is one factor which appears to markedly enhance fixation. It is believed that the greater the percentage of colloidal matter a soil may carry, just so much greater may be the amount of fixation—all other conditions being equal.

"Colloid," "colloidal," or "colloidal state" will be referred to from time to time. A few explanatory remarks regarding colloids may be appropriate. To be colloidal, substances must exist in extremely fine division. Fineness of division is imperative to the rendering of a substance capable of becoming colloidal. Smoke, for instance, is a colloidal suspension in the atmosphere of the solid residues remaining after imperfect combustion of organic substances. However, this solid material exists in a state of ultra microscopically fine division. The common lamp black pigment of commerce is obtained by bringing a moving cold surface in contact with the combustion products of imperfectly burned petroleum oil. Carbon in ultimately fine division, and hence colloidal, is deposited on the cold surface. Similarly, mist is a colloidal suspension of minute particles of water in air. A popular floating soap derives its floating properties entirely from mechanically introduced air distributed throughout the mass of the product in microscopic globules. In this case, air is colloidally suspended in the soap. Milady's facial cream carries a colloidal suspension of rose water in lanolin (oil) and bleached bee's wax, the "cream" being stabilized by a small amount of borax dissolved in the rose water. Mayonnaise dressing consists essentially of a colloidal suspension of lemon juice or vinegar intimately distributed in olive oil through the agency of agitation and rendered permanent by additions of egg albumen. Milk is a temporary suspension of butter fat in a watery whey aided by casein, the latter compound constituting one of the common commercial glues.

Clear red ruby glass—that used in photography and in railroad signal systems —owes its rich red color entirely to an extremely fine suspension of metallic gold in the glass. Were a large sheet of this glass to be remelted the gold could be recovered unaltered in a fine powder capable of being fused into a nugget. The metallic gold in this glass is present in a state of colloidal suspension.

Any soil containing appreciable amounts of finely divided clay will, when shaken with water and allowed to stand, become separated into fractions of granular particles and colloidal soil matter. The granular portion will settle out quickly to the bottom of the container. The colloidal portion will come down at a much slower rate, but in the interim the water above the settlings will remain dense and murky with suspended colloidal soil. Eventually two distinct layers (usually of different

color) may be observed in the bottom of the container. The lower layer will consist of distinct particles, readily distinguished by the eye. The upper layer will carry finely divided soil particles, many of which will be so minute that even a high-powered microscope would fail to enlarge the image sufficiently for detection.

We have seen that in the state of fine division solid, insoluble substances may readily be rendered colloidal in water, oil, air or other vehicles. Finely divided soil particles naturally assume the cololidal state in most of our lands.

But few question the finding that soil colloids are an important contributing factor in the fixation of applied soluble phosphates. One having access to an Experiment Station fixation kit may demonstrate to his own satisfaction the truth of this statement. Following the simple directions for making the tests he might compare a black sand or undecomposed lava ash with a heavy, rich colloidal soil from any source within the Islands. Without the colloids and provided no substances are present in the sample which may precipitate phosphates, he will find scant fixation. On the other hand, a highly colloidal soil may "fix" a great part or even practically all of the phosphate with which it may be brought in contact in making the test.

Since the colloidal state requires the presence of finely subdivided material, the size of soil particles is of significance in phosphate fixation. It is probably true that the percentage of finely divided soil has some bearing upon the rate of fixation. Some rather startling facts have been observed by Ward in connection with his studies of particle size distribution in Hawaiian soils. In many of them 50 to 60 per cent by weight of the soil is composed of fine particles having diameters less than one twenty-five-thousandth of an inch. More than 90 per cent of the total surface area of some of our soils is derived from particles of this size or smaller. In a consideration of these findings from the viewpoint of the tremendous surface areas of the soils involved it may be stated that there are more than one thousand square miles of particle surface existing in an acre-foot of such a soil. Since the phenomenon of fixation seems so intimately related to this matter of soil colloids and soil particle size it is believed that the relative magnitude of surface areas in various soils may prove of considerable importance in correlating and classifying soil types on a basis of their propensity to fix phosphates.

It has been shown that the fixation of applied soluble phosphates may occur within the colloidal fraction of a soil. It is also necessary to consider chemical reactions taking place in the soil which may result in the precipitation of applied soluble phosphates in the form of insoluble compounds. The precipitation may be brought about by reactions of the fertilizer with calcium salts, hydrated compounds of iron, compounds of aluminum, or other constituents normally present in the soil. Granted that such precipitations do occur; then it would be in order to learn if the roots of a plant could feed upon or utilize such precipitated compounds of phosphorus. Another investigator in Hawaii, in studying mainland soils, has been successful in synthesizing a compound of hydrated iron with phosphate which is extremely insoluble and which appears to be very similar in chemical and physical properties to the difficultly soluble phosphates formed in the soils after the application of a readily soluble fertilizer phosphate. This same investigator found that his synthesized insoluble phosphate was quite similar to a natural soil mineral known as dufrenite ($Fe_2[OH]_3PO_4$).

Surface Feeding

Greenhouse pot experiments designed by R. R. Ward and P. L. Gow are now in progress from which it is hoped to obtain information relevant to the ability of the cane plant to obtain its required phosphate from insoluble compounds. We had reason to believe that certain insoluble phosphates, such as raw rock and reverted phosphate, when applied to the soil would eventually become available for the use of the plant.

It has been suggested that fixation may occur in the soil by the formation of iron or aluminum phosphates following the application of a soluble phosphatic compound. Reiterating that only phosphates which are in solution in the soil water can be fixed, then, those forms of applied phosphate which do *not* dissolve in the soil solution *cannot* be fixed. But, if such compounds are not fixed and yet remain in the vicinity of the roots, can the plant feed upon them? If so, which of the insoluble phosphates are most available to cane? To answer these questions a silica sand culture experiment has been installed, using a number of different kinds of insoluble phosphates.

The treatments, at the rate of 300 pounds of phosphoric acid per acre, are described by Ward as follows:

1. Freshly precipitated tricalcium phosphate (phosphate of lime).
2. Freshly precipitated ferric phosphate (phosphate of iron).
3. Freshly precipitated aluminum phosphate.
4. Raw rock phosphate.
5. Reverted phosphate.
6. Superphosphate treated with sodium silicate and washed to remove soluble phosphate.
7. Raw rock phosphate treated with sodium silicate and washed to remove soluble phosphate.
8. Control; no phosphate.
9. Control; soluble sodium phosphate added in culture solution.

The materials were all thoroughly washed to remove any soluble phosphate which might have been present. (It should be noted that freshly precipitated tricalcium phosphate is very different, chemically and physically, from raw rock phosphate.)

All the pots are receiving complete culture solution minus phosphate, except those of Series 9, which, in addition, are receiving soluble phosphate as shown above.

Pure silica sand was used in the pots rather than soil in order to avoid the effect of any changes in solubility of the phosphates which might be caused by the soil. For the same reason, the culture solutions are applied by a constant drip method rather than intermittently in order to prevent the development of acidity in the unbuffered sand; to be more certain of this condition, a pound of commercial ground coral rock was added to each pot.

Five replications of D 1135 cane are being used for each of the treatments and are considered sufficient to show which of the insoluble phosphates being studied are most readily available to this variety, and how this availability compares with that of soluble sodium phosphate.

The plants used for the experiment are lalas which were cut from a field whose last fertilization was made more than a year and a half previous to the collection. After planting in flats containing silica sand the lalas were placed in a very fine spray of water to reduce transpiration until strong root systems were developed. At this time the plants were transferred to the experimental pots.

On June 8, 1933, some six months after planting, marked differences appeared in the response of the plants to the various treatments. The reverted phosphate series was far in the lead of any other of the insoluble forms. Response in this case was even slightly better than that shown by the plants receiving soluble sodium phosphate. Measurements were taken of the maximum height of each plant and the diameter of the largest stalk; the number of shoots on each stool was also counted. When each of the factors received equal weight in grading, and the reverted phosphate treatments were given an arbitrary score of 100, the various treatments were classified by Ward as follows:

Reverted phosphate	100.0
Sodium phosphate solution	96.5
Freshly precipitated aluminum phosphate	76.3
Freshly precipitated ferric phosphate	61.2
Superphosphate plus sodium silicate	70.4
Freshly precipitated tricalcium phosphate	66.7
Raw rock phosphate plus sodium silicate	57.0
No phosphate	54.3
Raw rock phosphate	50.3

At the present time, October 12, 1933, the experiment is showing interesting developments. We believe it has been definitely established that D 1135 cane can utilize tricalcium, ferric, aluminum and reverted phosphates. In fact, the ferric, aluminum and reverted phosphate series show more stalk development and more millable cane than do those receiving soluble phosphate in the culture solution, although the latter show on an average a larger number of stalks per pot. A detailed discussion of the various treatments in the order of their responses at the present time is quoted below from a report by Gow, dated October 12, 1933:

Ferric Phosphate: **This treatment, while it always showed good response, was outstripped by reverted phosphate, sodium phosphate and aluminum phosphate until the early part of July, when it began to show unusually rapid growth. During the first month of the experiment some of these plants showed rather definite evidence of plugging of the vascular bundles with iron. This was quickly cleared up by increasing the amount of potash in the culture solution, but it may explain why the ferric phosphate treatment tended to lag behind some of the other treatments during the early months of the experiment. At present this treatment is outstanding from the standpoint of size of stalks and total amount of millable cane.**

Aluminum Phosphate: **This treatment is somewhat poorer than the ferric phosphate series and is little, if any, better than the reverted phosphate. Like the ferric phosphate plants, they showed considerable evidence of plugging due to deposition of aluminum salts—a condition which was quickly cleared up by increased potash. These plants have also pulled ahead of other treatments in the past two months.**

Reverted Phosphate: **At the end of the first month this treatment was much the best of all and continued to hold this place during the second, third and fourth months. However,**

during the fifth month the development of these plants in relation to other treatments showed a tendency to slow up somewhat. At present they are still making good growth, although the young suckers show an inclination to die off within a week or two after sprouting. This tendency may disappear after the end of the hot weather, as the death of these suckers seems to be correlated with periods of especially high temperatures in the greenhouse. Reverted phosphate is still one of the best treatments and bids fair to maintain this place.

Sodium Phosphate Solution: While showing very good growth and a marked tendency to stool out, this treatment does not show at present the remarkable stalk development to be observed in the case of the preceding three treatments. Since the second month these plants have all showed unmistakable symptoms of iron deficiency, a disorder which we have been unable to entirely correct. Attempts at aleviation have been made by applying ferric citrate, ferric tartrate, ferrous tartrate, ferrous sulfate, ferric lactate and colloidal ferric hydroxide, and while examination of the sand in these pots shows an excess of iron in an available form, these particular plants appear to be unable to take up enough iron for their needs. The symptoms do not appear to be serious, consisting as they do of somewhat chlorotic stripes along the leaves, and there is no evidence of acute suffering for lack of iron. It is quite possible, however, that this inability to absorb sufficient iron may account for the failure of these plants to show up better than the four preceding treatments.

Tricalcium Phosphate: Of the five replications comprising this treatment, two are mediocre, two are fairly good and one is the best plant in the experiment. There is no doubt that this form of phosphate is at least somewhat available since none of the plants are showing signs of acute phosphate deficiency, but the ability to utilize this form of phosphate appears to depend somewhat on the individual plant.

Superphosphate plus Sodium Silicate: This treatment has shown a marked gain in the past two months, both in the matter of stalk growth and of development of new stalks. We feel that it is too early to form a definite opinion concerning it, but it appears to offer a good deal of promise.

Raw Rock plus Sodium Silicate: This treatment is definitely better than raw rock alone and bids fair to continue improvement at a greater rate than the raw rock. This result cannot be due to the presence of sodium silicate in the pots since it was carefully washed out after treating the raw rock previous to adding the fertilizer to the pots. It should also be noted that sufficient silica for the needs of the plants is being supplied in the culture solution. The most satisfactory explanation of the superiority of these pots over those containing raw rock alone seems to be that the sodium silicate has some chemical effect on the raw rock phosphate which renders it more available for plant assimilation.

Raw Rock Phosphate: Measurements taken June 8 showed the raw rock treatment to be somewhat poorer than the no phosphate treatment, indicating the possibility of a mildly toxic effect of the raw rock. However, at present the raw rock pots are showing definite response and are markedly better than the no phosphate pots. It is interesting to note that this improvement did not become noticeable until the beginning of the sixth month and that during this month it has been so rapid. It is unfortunate that the plants are now becoming so rootbound that the experiment will have to be discontinued at the end of October. This "delayed availability" of raw rock merits further study.

No Phosphate: These plants are all slowly dying. They continue to put out new leaves at a very slow rate, but the stalks are becoming progressively smaller, and in many cases the joint between leaf sheath and blade is lower on the newer leaves than on the older ones. The leaves are extremely narrow and of the somewhat grayish tinge that appears to be characteristic of phosphate deficiency.

Since it is important to the validity of this study that the pH of the pots be kept neutral or slightly alkaline in order that the insoluble phosphates remain insoluble, Gow recovered samples of the solution as it dripped from the bottom of the various pots to determine if there were any noticeable variation in pH as the solution percolated through the sand about the roots of the plants. The remark-

able result of these determinations was to show that, while the solution going into the pots had a pH of exactly 7.0, the solution leaving them gave a reaction of 7.8. Moreover, this finding was independent of the treatment and of the rate of percolation, all of the pots in the experiment yielding solutions of approximately the same pH. This increase in alkalinity cannot be attributed to the calcium carbonate which was mixed with the sand as the pH of the original culture solution was regulated by keeping the solution in contact with calcium carbonate for 24 hours. Therefore, it must be attributed to the effect of the plant roots upon the solution as it flowed around them. This effect is of interest and merits further study.

On the whole, the results to date have been extremely satisfactory and we feel safe in stating that the primary purpose of the experiment has been accomplished. Our efforts were directed to learning the answer to the question: Which water insoluble forms of phosphate are available to cane plants under conditions of pH which will insure continued insolubility?

From a practical viewpoint, the behavior of reverted and raw rock phosphate point to the possibility of using a combination of these two fertilizers to by-pass fixation. Gow suggests that the reverted form should supply the needs of the young cane during the first 6 or 8 months and the raw rock may well carry on from this point. Further study may be necessary to determine how these materials must be handled when the further complication of the soil environment is added to the system; but the results of this experiment indicate the chemical principles upon the basis of which fixation of phosphates may be averted.

Effect of Molasses and Silica Upon Fixation

Ayres has studied the effect of several treatments upon the phosphate fixing characteristics of soils. Two substances covered in his studies, namely, molasses and soluble silica, were found to effectively reduce fixation. The duration of this influence has not as yet been determined. While applications of soluble silicates are pronounced in effecting a reduction of phosphate fixation, silica does not appear to compare favorably upon an economic basis with equivalent quantities of soluble phosphates.

Ward, too, has found that the addition of silica acid to soils greatly reduces their fixing power for phosphates.

His research supported findings of other investigators who have shown that the ratio of silica to iron and aluminum in the soil colloids furnishes a measure of the acid or base absorbing power of the colloids. If this ratio is high, bases are fixed to a large extent and if it is low, acids such as phosphoric are more strongly fixed. The ratio of silica to iron and aluminum is extremely low in Hawaiian soils, and, as a consequence they should fix phosphate to a large extent. Such we know to be the case. If the ratio could be increased, the fixing power for phosphate should be decreased.

It was with this idea in mind that soils were experimentally treated with silicic acid. Ward's laboratory studies showed that the amounts of phosphates fixed by the treated soil were very much less than quantities fixed by the original soil.

We have learned that even extremely large applications of phosphoric acid, in the form of soluble phosphates, to our high fixing soils will result in from 95 per

cent to nearly complete fixation within a matter of weeks. During this interval an equilibrium tends to become established between the very small percentage of soluble phosphates remaining in the soil solution and that which has become fixed within the soil complex. The ratio of fixed phosphates to soluble phosphates may be different, and probably is different for all distinct soil types. Soils may be distinguished very readily by directing attention to the relative amounts of phosphate which are not fixed. As a specific example Ayres, in comparing the fixing ability of a number of soils, found that when phosphate was added at the high rate of 5,000 pounds per acre-foot the fixation, at the end of five days, ranged from 98.33 per cent to 99.95 per cent. But, while these values appear to be of the same order of magnitude it will be noted that thirty-three times as much P_2O_5 remains unfixed in one soil, the lowest fixing specimen, as compared with the highest fixing soil. This fractional residue of unfixed phosphate is vitally important in supplying the plant with available nutrients.

In the laboratory, Davis has been able to leach out a portion of the small amount of the soluble phosphate remaining in the soil solution after a soil has been treated with a phosphate, and fixation has occurred. In doing so, however, he found that a portion of the fixed phosphate becomes disengaged from the soil complex and eventually reappears in the soil solution. Forces are thus operating in the soil which tend to restore an equilibrium between the phosphate remaining fixed and that which is dissolved in the soil solution. As a result of leaching by the passage downward through the soil of rain or irrigation water this equilibrium becomes disturbed by the removal of a certain amount of the phosphate in solution. Then reactions in the soil tend to reestablish that equilibrium as already mentioned. If this be true, it follows that were the cane plant to remove phosphate from the soil solution instead of its having been washed by leaching, the equilibrium should in time be reestablished. The fixed phosphates then would function to a variable extent as a supply for the use of the plant. While it is probably true that such reactions do occur in the soil, it is also quite obvious that some excessively high fixing soils do not allow the readjustment of equilibrium reactions to take place fast enough to supply the needs of the growing plant. In such a case we do have phosphate starvation in spite of heavy applications of soluble phosphates because the amount of phosphate which remains soluble is very small and likewise because of the slow rate at which the fixed phosphates may be given up by the soil complex to the soil solution. The staff of the department are at present devoting attention to this study.

The Rate of Phosphate Fixation

We may also distinguish one fixing type of soil from another by studies of the rate at which applied phosphates may be fixed. In a Manoa soil of very high fixing power Davis found that when treatment consisted of a very large application of phosphate 80 per cent was fixed in twenty-four hours in a laboratory experiment involving constant agitation. Ninety per cent had been fixed at the end of 4 days, 95 per cent at the end of 8 days and 96 per cent at the end of 15 days. After a period of six weeks, fixation was still increasing, but very slowly. Davis suggests, however, that in the field the rate undoubtedly would be very much slower and would depend upon a number of related factors.

In a cooperative study with J. N. P. Webster, Ayres made a number of soil extractions from specimens obtained four months after experimental treatment with graded amounts of a soluble phosphate upon a high fixing area of Kauai. He reports the following data:

Treatment (Lbs. P_2O_5/acre)	Recovered (in single extraction Lbs. P_2O_5/acre)
0	0
2000	2.5
4000	50.0
6000	97.5
8000	250.0

It is significant to note that quadrupling the application, i.e., from 2000 to 8000 pounds, increased the water soluble P_2O_5 not *four*, but *one hundred* times—these findings having been made four months after application. Thus it appears that even in soils which have very high fixing power and providing heavy applications of phosphate are made, a considerable amount of soluble nutrient may remain available to the plant during the progress of fixation.

On the other hand, as mentioned previously, we have found that if phosphate present in the soil solution is removed by leaching, a release of phosphate from the fixation complex to the soil solution follows and that by successive leaching a large quantity of the fixed phosphate can be brought back into solution. Where larger amounts have been fixed, it is possible to release greater quantities.

The progress in the greenhouse experiment of surface feeding by cane on insoluble prosphates indicates that sugar cane can derive ample phosphate from the simpler, insoluble phosphate compounds. On the other hand, our researches have caused us to infer that very probably phosphate is absorbed by some of our soils in such a way as to form complex compounds which are probably not as soluble nor as available to plants as the simpler ones.

Soil Organic Matter as Affected by Applications of Phosphates

It has been known for a number of years that strongly alkaline solutions extract large amounts of dark colored organic matter from soils. This is usually described as organic humus. The term "humic" or "humus" is indefinite in meaning and covers a mixture of several slightly known and some unidentified compounds.

It appears that not alone strongly alkaline solutions, but probably any well-buffered* solution, even at a pH as low as 3.0 to 4.0, will extract some organic matter from soil. Unbuffered neutral or moderately acidified solutions, such as those containing nitrate of soda, or muriate of potash, do not have any appre-

* The term "buffer" has appeared previously and will be used occasionally in the discussion which follows. A buffer is a substance which, when added to another in a solution, causes a resistance to any change of acidity or alkalinity, even upon the addition of acids or alkalies. Some common buffering agents are: animal blood, certain acetates, phosphates, borates, etc.

ciable extracting power upon soil humates. It is also true that nitrates, chlorides, sulfates, etc., are not absorbed or fixed by soil to the extent that are phosphates.

Solutions of phosphates, such as ammonium phosphate, are very well buffered. Davis has found that such solutions can extract large amounts of organic matter from a soil. He found that the amount of matter extracted depends somewhat upon the pH but more upon amount of phosphate applied and is not very great for such applications as 100 pounds P_2O_5 per acre. But for larger applications considerably more organic matter becomes soluble. Davis has determined that if muriate of potash, sulfate of ammonia, etc., are applied along with the ammophos, the extraction is decreased somewhat, but not very greatly. Furthermore, even when these slightly buffered compounds have been applied, successive leaching with pure water will result in removal of large amounts of organic matter, that is, provided that sufficient ammophos has been employed.

It may develop, therefore, that in practice wherever large amounts of ammophos are applied to a high fixing soil, either singly or along with other fertilizer, not alone will a great deal of organic matter be dissolved, but subsequent leaching by rain or irrigation may carry it into the soil solution where it may be utilized by the plant or pass into the subsoil. We do not at present know the agricultural significance of this finding, but hope that additional light will be thrown on it in future researches as planned by Davis and developed from this important lead.

Base Exchange in Fixation

The subject of base exchange or base replacement has been studied extensively all over the world and to some extent by ourselves. We do not propose to discuss this subject except in the narrow way in which it is related to phosphate absorption.

If a solution of ammonium sulfate or potash nitrate is applied to a soil, a part of the ammonium or potash will be absorbed. It is believed to have reacted in some way with solid constituents of the soil containing sodium, potassium, magnesium, calcium, etc., in such a way that some of the latter group are exchanged for the introduced ammonium or potassium and are therefore made soluble, whereas pure water might bring very little of these bases into solution.

When ammonium or potassium *phosphate* is applied to a soil an amount of ammonium or potassium, it is thought, replaces other bases to an extent of at least five or ten times as much as would occur were a sulfate or muriate used instead. It appears that in the case of phosphate fixation, there is a corresponding fixation of at least part of the basic group. The agricultural significance of these facts is not at present clearly understood, but it is evident that they may be of outstanding importance with respect to such matters as the form, time and number of applications of phosphate fertilizer which should be made for any given soil or crop during a growing cycle.

Geographical Variability of the Phenomenon in Hawaii

Excessive phosphate fixation is found in the soils along the Hamakua coast. We believe it would prove of value to study pronounced characteristics of fixation in this vicinity and to correlate data in a comprehensive manner so as to consider the problem from a geographical viewpoint as we pass from the high fixing soils in

this dry belt progressively through the rain belt to Hilo. The soils of the Manoa substation are also very high phosphate fixers. But meager supplies of readily soluble potash are found in certain other Manoa soils. A study in this region, therefore, involves not only phosphate fixation, but includes the subject of the deficiency of potash. On the island of Kauai, Ayres has determined that fixation is most pronounced in the soils of higher elevation in the district of Kilauea. In his survey of that island by plantations from Kilauea to Makaweli, it was learned that in general and with normal soils the degree of fixation became less pronounced in moving progressively west toward Makaweli. Fields were found in the latter region where fixation of applied phosphates was relatively low. It was also found that the most fertile areas in this district were regions where fixation was least pronounced and that in growth failure or other poor areas the propensity to fix phosphates was markedly greater.

It was also shown by Ayres that the subsoils of Kauai are capable of much greater fixation than are the corresponding surface soils. This information is of importance when considered in connection with the fertilization of typical shallow surface soils of that island.

Conclusions

No panacea for phosphate fixation can be prescribed. Nevertheless, certain possibilities suggest themselves, some of which have been tried out in practice. It seems logical that each soil should be considered as an individual problem instead of attempting to apply a general rule.

The cases which naturally arise when one considers the relation between fixation and availability may possibly be grouped into four main types:

(1) The soil has a relatively low fixing power and a high content of phosphate, a condition frequently found in lowland soils. This soil may be fertile if there are no other difficulties and, in any event, it seems unlikely that much response to phosphate fertilization should be expected.

(2) The soil has a low relative fixing power and a low content of phosphate. This soil should probably respond to soluble phosphate fertilizers, provided that some other difficulty is not the limiting factor in cane growth. Under these circumstances the type of phosphate used may be very important.

(3) The soil has a moderately high fixing power. Slight applications of soluble phosphates, such as 100 to 200 pounds of phosphoric acid, may not give response, although larger but in many cases economically reasonable applications, such as 300 to 500 pounds, may increase the yield, other things being equal. It is reasonable to believe that once the level of phosphate content has been raised by an application of 400 pounds of phosphoric acid, for example, subsequent applications can be much lighter. Again, the form of phosphate chosen may be of very great importance.

(4) The soil has a high fixing power. In this case if sufficient soluble phosphate were to be applied undoubtedly it would be possible to overcome the fixation. But the amounts required may be absurdly uneconomical. In some cases, it has been found that lesser amounts will show no response at all, although phosphate deficiency may be pronounced.

As one means of side-stepping fixation it may be found possible to substitute moderate amounts of *insoluble* phosphates for the soluble forms. Insoluble phosphates will not be fixed by the soil. Certain of these compounds, notably reverted phosphate, appear at present to be very good sources of phosphatic food, at least under certain conditions. In a high fixing soil a combination of reverted and raw rock may prove an ideal phosphatic addition.

While soluble silica has been shown to effectively reduce fixation its employment for this purpose is uneconomical in view of the present prices of silica and of phosphates.

Soils treated with normal quantities of molasses have a lower fixing capacity for phosphates than untreated soils. The duration of the effect has yet to be determined.

Where subsoils are higher in fixing capacity than the corresponding surface soils it is important, when applying soluble phosphate to insure its placement in the lower horizon of the surface soil providing this layer is of sufficient depth to surround adequate portions of the feeding roots.

The addition of successive increments of phosphate to a soil results in an increasing proportion of the total applied phosphate remaining unfixed and hence available for use by the plant.

One of the most promising methods of applying phosphate in a form such that it will be available to the cane plant, but will not be fixed by the soils is believed to consist of the use of fertilizer briquettes carrying a *soluble phosphate.* It has been demonstrated that properly made briquettes will remain intact in the soil for some months and will very slowly yield their fertilizer nutrients to the plant roots. A mass of roots completely surrounding a briquette will protect it from the fixing soil and will have the first chance to absorb the phosphate fertilizer as it slowly leaches from the briquette. In addition, potash and nitrogen can be supplied in the briquette. In soils from which potash is very rapidly leached the briquette will aid in the retention of this necessary plant food.

Summary

1. Heavy phosphate fixation may be anticipated in a highly colloidal soil.

2. Applied soluble phosphates may be precipitated in a sandy or other soil in an insoluble form. In such a case the phosphate may or may not be rendered difficult for the plant to absorb.

3. Soil particle size, total soil areas exposed to action of soil solution and ratio of colloids to non-colloids in any soil are factors of importance in the phenomenon of phosphate fixation.

4. The cane plant can and does obtain adequate quantities of phosphate from insoluble granulated phosphates when grown in quartz sand and supplied at the same time with a balanced ration of other essential foods by nutrient solution. In the order of availability to the cane plant in sand cultures may be mentioned: Reverted phosphate, aluminum phosphate, ferric phosphate, tricalcium phosphate, and, lastly, raw rock phosphate. The responses to these forms of insoluble phosphates in soil studies have yet to be determined.

5. There is reason to believe that the crop can feed upon applied soluble phos-

phates during the time that fixation is taking place in the soil. The duration of this period is variable for soils having different characteristics.

6. Evidence is at hand supporting the probability that even after applied soluble phosphate have become fixed in the soil and the plant absorbs the available supply in the soil water solution additional phosphates redissolve from the fixed reserve and enter the soil solution again. The process appears to be continuous, and in the absence of removal by leaching, or by the plant, the action will continue until a balance has been established between the phosphate in the soil solution and that residing in the fixed reserve. When the rate of transfer is below the requirements of the plant (as it is in many cases) then phosphate starvation occurs.

7. In many respects moderate fixation of phosphates by the soil is of distinct advantage to the crop and grower. The problem of excessive leaching is absent—in some cases the phosphate nutrient may pass into the soil solution in continuous and progressive amounts as it may be needed. The fixed phosphate may thus function as a near-by reserve immune from leaching or other loss.

8. The choice of type of phosphate fertilizer may eventually prove of great importance. The solubility of other nutrients and the movement of soil organic matter into the soil solution are factors which appear subject to some control by the judicious use of commercially available phosphate types.

9. In many soils phosphate fixation is severe enough to result in deficient nutrition when fertilizer applications of 100 to 200 pounds of phosphoric acid, as soluble phosphate, are made, but if the degree of fixation is not too great, larger, but moderate applications such as 300 to 500 pounds may be sufficient to support good growth.

10. In soils which have very high fixing power, it is possible that phosphate applied as an insoluble compound may be sufficiently available and yet not be fixed by the soil.

11. We believe that possibly fertilizer briquettes will constitute a very useful means of applying insoluble phosphates in conjunction with other nutrients.

12. As a rule subsoils show a higher fixing ability than the corresponding surface soils.

13. Disregarding convenience and economy, it has been found that molasses and/or soluble silica are effective in reducing the phosphate fixing capacity of soils.

14. The larger the application of soluble phosphate to a given soil, the greater is the proportion thereof which remains in water soluble, and hence available, form.

NOTE: Messrs. Davis, Ayres, Ward and Gow have in preparation detailed papers supplementing topics referred to or commented upon in this discussion.

Variation of Mineral Content of Sugar Cane With Age and Season

By Arthur Ayres

The need for a more comprehensive understanding of the manner in which various factors influence the mineral content of sugar cane is becoming increasingly evident. Problems are constantly arising which involve rates of nutrient absorption, inadequate nutrient supply, and the composition of canes produced under greatly varied environmental conditions. Frequently the problem is pathological. In the cane plant, for example, a condition of disease may result from factors associated with a deficiency of some one or more nutrients. The existence of such a pathological state may often be verified by supplying the deficient element in amounts adequate to restore the plant to normalcy. Or, again, the physiological condition coincident with the presence of the malady may be induced in otherwise healthy cane plants by depriving them of the element in question. The chemist may cooperate in the pathological study by examining chemically the mineral content of abnormal specimens. Obviously, however, before he can state by what measure the concentration of a particular nutrient departs from that found in the normal plant he must have a knowledge of the composition of the normal plant as well as of the factors by which it is influenced.

It is the purpose of the investigation discussed in this paper to study the effect of age and season upon the nutrient content of the sugar cane plant. This work may also properly be considered as preliminary to a study now in progress which is designed to greatly augment our very limited knowledge of the rates of absorption of the major soil nutrients. The latter phase of the investigation bears directly upon the important question of time of fertilization.

Maxwell (1), at this Station (1900); Browne and others (2), in Louisiana, and more recently investigators both here and elsewhere have shown conclusively that the ash content of sugar cane differs very greatly with different varieties, even when grown under practically identical conditions of soil and climate. The work of Hall (3), at Rothamsted (1905), established the fact that the composition of plants in general is a function of their age. Johnson (4) cites voluminous data which support this contention. Cane composition studies reported by Stewart (5), Ayres (6) and more recently by Deomano (7) in the Philippines, amply illustrate the influence of age and season upon the mineral content of sugar cane. It is a well-known fact that the concentration of nutrients in the soil solution affects their rate of absorption by the plant. It is further known that the condition of the individual plant, that is, whether healthy and vigorous or diseased and stunted, is a factor affecting the amount and composition of its ash.

From these considerations it is apparent that a proper understanding of the subject must of necessity include a knowledge of the manner in which these factors influence the mineral composition of the sugar cane plant. Realizing the need for such an understanding and believing that a study of the effect of age and season upon absorption should logically precede inquiry into related factors, an experi-

ment, designed to yield this information for the variety H 109, was installed in the Makiki area in the fall of 1931. While the experiments at the Oahu Sugar Company, Ltd. (5), and the Waipio Substation (6), as previously stated, gave evidence of pronounced variation in the composition of the ash there was some

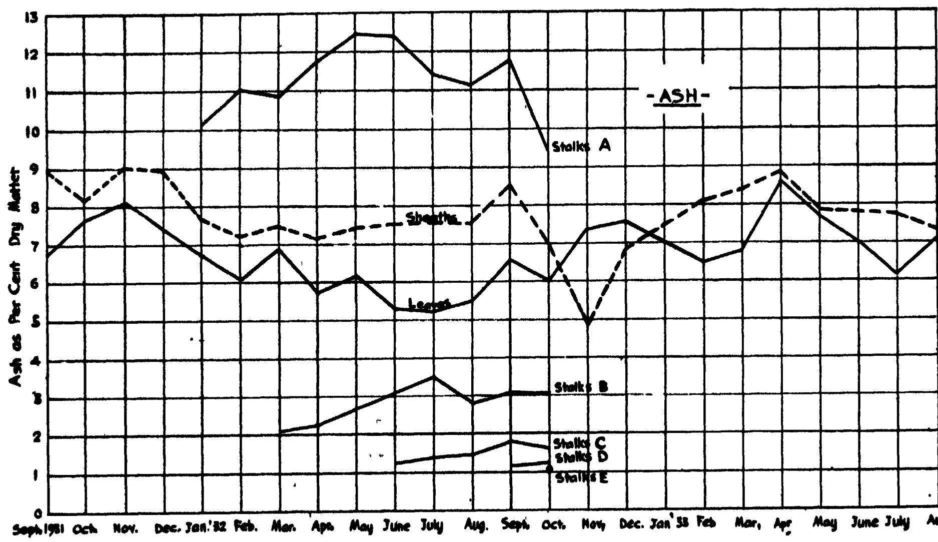


Fig. 1. A comparative study of the ash content of different parts of the cane plant at various stages of growth. Data presented as percentage of dry matter.

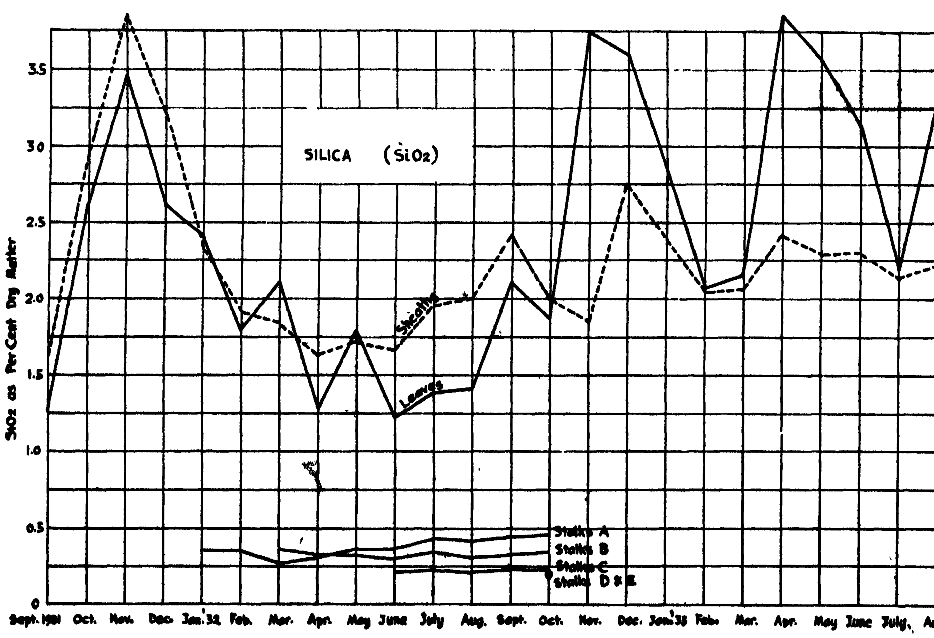


Fig. 2. A study of the silica content of different parts of the cane plant as the crop proceeds. Data presented as percentage of dry matter.

uncertainty as to the part played in the observed changes by the applications of potash, phosphates and their accompanying elements. In order to eliminate the necessity for applications of phosphoric acid and potash, with the resultant effects upon nutrient absorption and the equilibrium of the soil system, a fertile piece of

Makiki soil was selected for this work. One per cent citric acid extract of this soil yielded upon analysis the following results (dry weight basis):

0.402	0.776	0.026	0.236
Silica (SiO_2)	*Lime* (CaO)	*Potash* (K_2O)	*Phosphoric Acid* (P_2O_5)

Experimental

The experiment, involving approximately 1000 running feet of line, was installed for us by the agricultural department in Field 8, Makiki, on August 22, 1931. The resulting germination of the seed was excellent. Adequate guard lines protected from border effect the region from which samples of plant material were to be taken for analysis. Cane samples were obtained at monthly intervals with a single exception during the period of tasseling, beginning one month after planting and continuing until the crop was harvested on August 22-23, 1933. The samples were selected in accordance with a definite, predetermined plan, which, it was felt, was well suited to the purpose of the investigation. The number of stalks taken at each period was 20, except at the ages of 1 and 2 months, when, for purposes of analysis, additional material was required. Not more than a single stalk was removed per stool and at all times effort was made to obtain composite samples which represented all of the plant material available for the purpose. The plants comprising the sample were segregated into portions, when the material was present, as follows:

Description of Plant Part	*Herein Referred to As*
Green portions of leaves	Leaves
Green portions of leaf sheaths	Sheaths
From tip of growing point six inches down stalk	Stalks (A)
From base of Stalks A three feet down stalk	Stalks (B)
From base of Stalks B three feet down stalk	Stalks (C)
From base of Stalks C three feet down stalk	Stalks (D)
From base of Stalks D three feet down stalk	Stalks (E)
Fuzz	Fuzz
Tassel stalks	Tassel stalks

The division of the cane stalks as outlined above is largely arbitrary and was made in the stated manner for the purpose of determining the variation in mineral content within this physiologically continuous system. The greatest care was exercised in the preparation of the samples to remove all adhering foreign material which would affect the analytical results.

The fertilization of the experiment was as follows:

September 29, 1931	NH_4NO_3	N = 50 lbs./acre
November 27, 1931	NH_4NO_3	N = 100 lbs./acre
February 7, 1933	$(NH_4)_2SO_4$	N = 50 lbs./acre
	Total	N = 200 lbs./acre

The crop passed through the first winter without tasseling. As a consequence of tasseling the second winter, with the resultant abundance of lalas and the associated changes in the system which we had been examining, sampling of all parts

of the stalk was discontinued at that time. The basic analytical data resulting from the study are presented in the table in two forms; in one case as per cent of the dry matter and in the other as per cent of the ash. Both for reference pur-

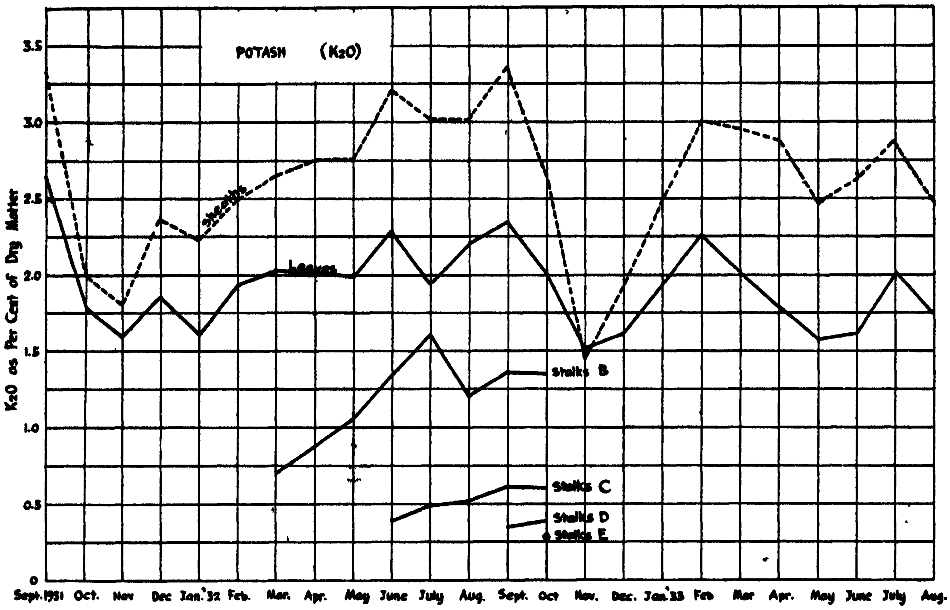
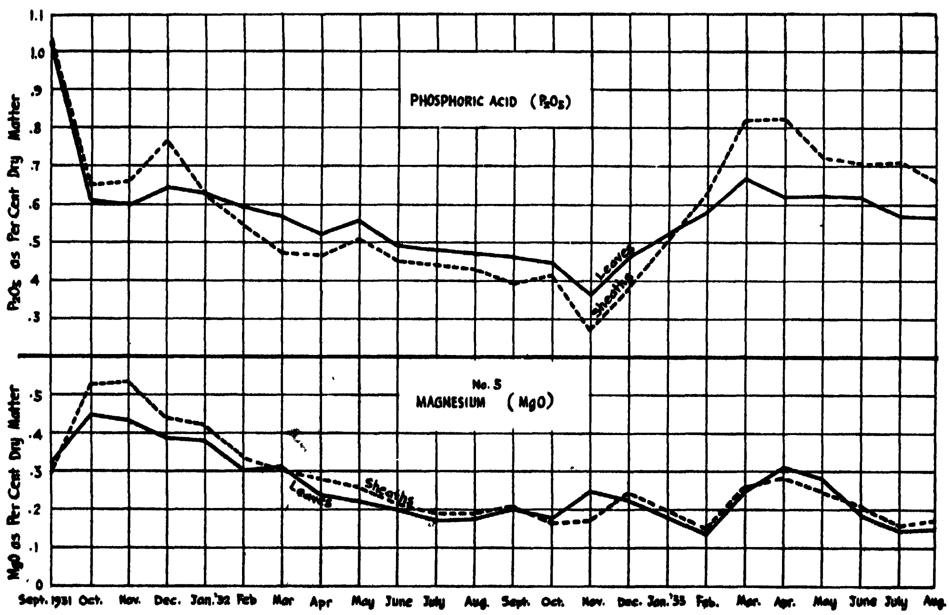


Fig. 3. A study of the potash content of various parts of the cane plant. Results expressed as per cent of dry matter.



Figs. 4 and 5. A study of the phosphoric acid and magnesium content of the leaves and sheaths of the cane plant. Results expressed as per cent of dry matter.

poses and in order that the reader may visualize at once the nature of the changes which were found to occur in the mineral composition of the crop, much of the data have been presented graphically. (The writer was ably assisted in the analytical work by E. K. Hamamura, analyst.)

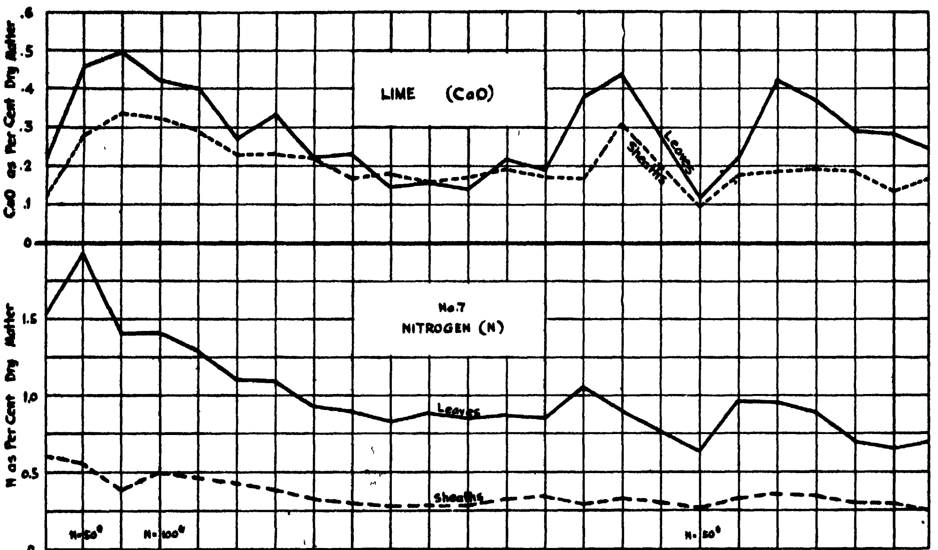
Discussion of Results

From even a cursory examination of the results it is evident not only that the concentrations of the inorganic nutrients in the various parts of the cane plant are very far from being constant throughout the course of the crop, but the behavior of certain elements with respect to their regional distribution is very unlike that of certain others. For instance, between the ages of 1 and 3 months, while the content of phosphoric acid and of potash in the dry matter of the leaves decreases by approximately 40 per cent, that of magnesium rises by some 35 per cent, that of lime by 145 per cent and of silica by 175 per cent. Throughout the entire period of growth there is maintained a most striking similarity in the manner in which silica, lime and magnesia vary, while in direct contrast, is that of the nutrient potash, the concentration of which in the leaves and sheaths varies inversely with that of the three constituents just named. With the noteworthy exception of nitrogen, the concentrations of nutrients in the leaves and sheaths are of much the same order. Marked similarities are found in the general direction and rate of change of mineral content in these two organs of the cane plant.

The composition of the stalk in the vicinity of the growing point (top 6 inches) is very different from that of any other part of the plant. While the ash content of the more remote portions of the stalk is in the neighborhood of 1 per cent, in the section just referred to it runs as high as 12.5 per cent of the total dry weight. This region is found to contain the highest concentrations of the elements nitrogen, calcium, magnesium, phosphorus and potassium. In view of the large quantities of potash which are always found in the meristem and active organs of plants in general, it is not particularly surprising that we find this nutrient alone comprising as high as 6 per cent of the total dry weight, or 45 per cent of the ash in this region of pronounced cellular activity. Reference to Fig. 1 shows a very marked drop in mineral content as we pass from the top 6 inches of stalk to the succeeding 3-foot segments. This diminution in the ash content is maintained, though in ever lessening degree, as the base of the stalk is approached. Not only is this true of the ash, but it is equally true of each component of the ash, as well as of nitrogen. However, this seemingly consistent relationship no longer obtains when we eliminate from our considerations sugars, fibers and other combustible organic materials and reëxamine the situation on the basis of the composition of the ash. In this clarified picture we see that the less readily translocated substances silica and phosphoric acid are actually increasing in the ash as we move in the direction of the older part of the stalk, whereas the concentration of the very mobile potash rapidly diminishes. This relationship is very clearly evidenced in Fig. 13.

It is of interest to note that sharp changes occur in the direction and rate of change of the mineral composition of the leaves and of the sheaths at roughly the following periods: 3, 15, and 20 months. Generally, these changes are more pronounced in the cases of those elements which are found in the plant in larger amounts. It will be seen that the second period (15 months) is just 12 months or one year after the initial period. This suggests a seasonal effect. At the same time it is quite possible that the sharp increases or decreases which abruptly ceased at the end of the first 3 months were associated with the development of

the foliage and that the equally sharp changes observed at 15 months (November 23, 1932), were the result of physiological processes related to the preparation of the cane to tassel. The changes of the third period referred to may have resulted from the application of spring nitrogen in February, 1933, with the



Figs. 6 and 7. A study of the concentrations of lime and nitrogen in different parts of the leaves; shown in percentage of dry matter at various stages of the crop.

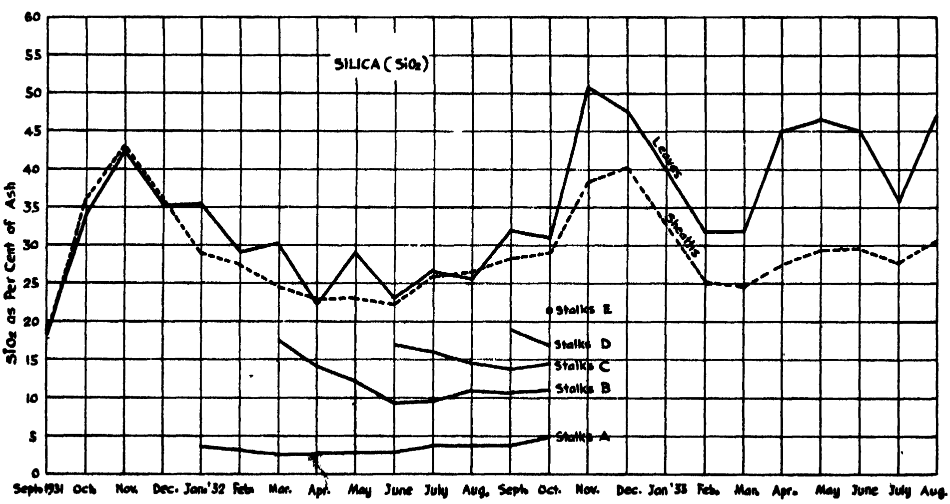


Fig. 8. Variation in silica content of the cane plant with development of the crop. Results expressed as percentage of ash.

resultant stimulation to growth, the latter having practically ceased coincident with tasseling.

Following is a hypothetical case which illustrates the manner in which information of the nature obtained in this work may be practically employed. Suppose specimens of H 109 cane grown under conditions similar to those of this experiment and suffering from a malady believed to result from insufficient potash, were subjected to analysis. Assume further that upon analysis the leaves

were found to contain potash in an amount equal to 1.5 per cent of their dry weight or, say, 20 per cent of their ash content. Is there, or is there not, a deficiency of this nutrient in the diseased plant? Reference to the data as pictured in Figs. 3 and 9 indicates that a potash content of the value found in the specimen is normal for certain stages of development, but decidedly below normal for others. Now, knowing the age of the specimen and bearing in mind the assumption that it was grown under conditions similar to those which obtained in this experiment, we can say, within certain limits, whether the pathological condition in the plant is, or is not, associated with a potash deficiency. From this simple example the necessity for investigation along lines similar to those of the present

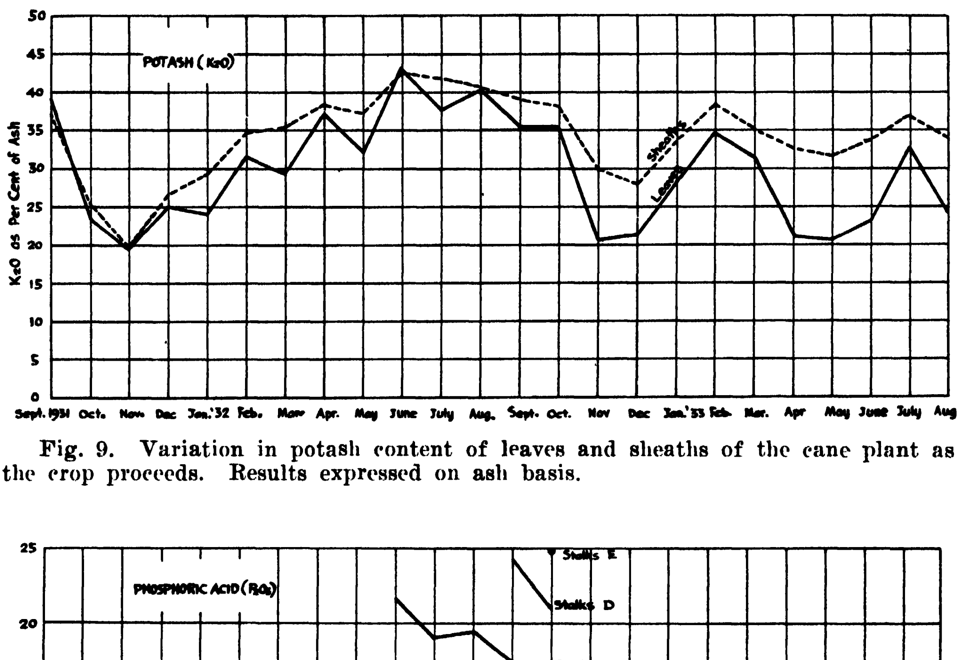


Fig. 9. Variation in potash content of leaves and sheaths of the cane plant as the crop proceeds. Results expressed on ash basis.

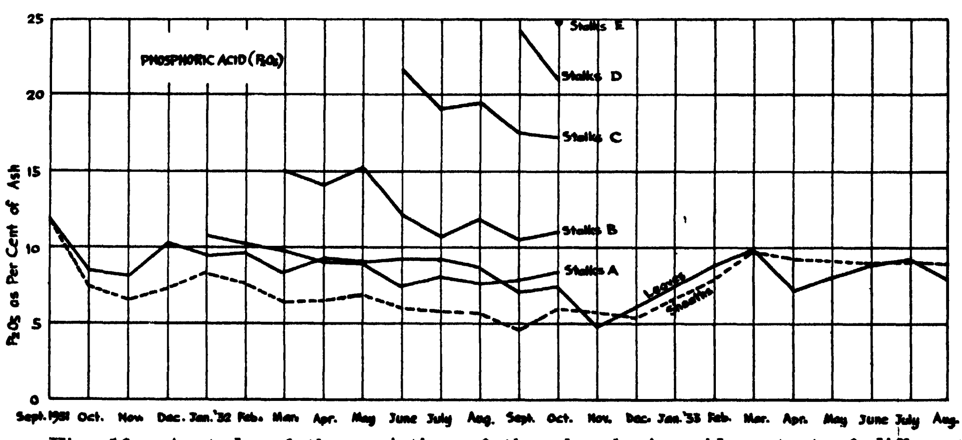
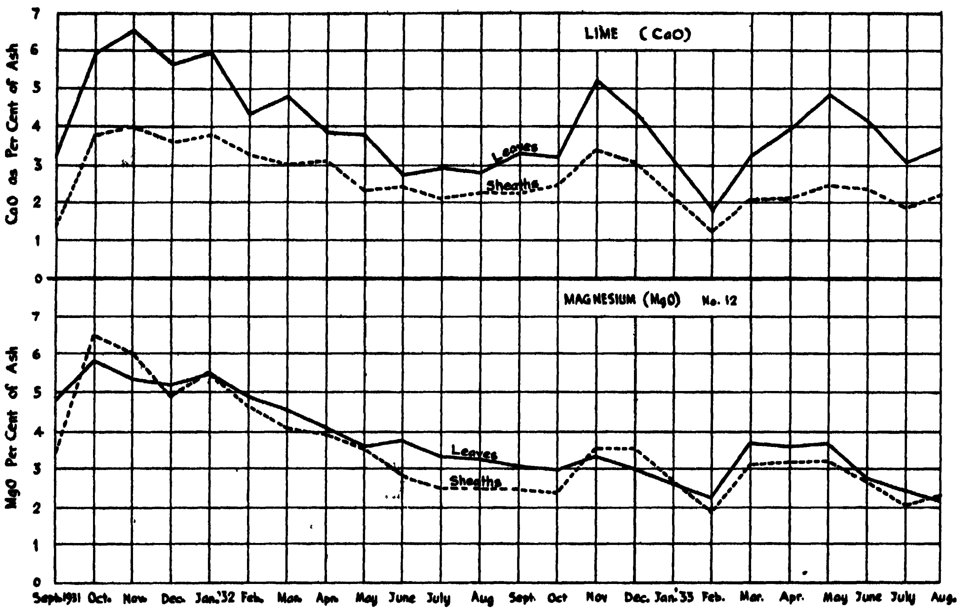


Fig. 10. A study of the variation of the phosphoric acid content of different parts of the cane plant as the crop proceeds. Results expressed on basis of ash.

study becomes apparent if we are to be in a position to deal adequately with cases of unbalanced nutrient conditions in the cane plant resulting from disease, soil nutrient deficiencies, etc. It is highly probable that, as W. W. G. Moir has repeatedly suggested, we may find the principal consideration to be not the actual concentration of a given nutrient, but rather the quantitative relationship which the element in question bears to the other mineral components of the plant.

The experiment is to be continued as the ratoon crop through the same cycle

as that of the plant. We will thus be enabled to compare, at monthly intervals, the mineral composition of the two crops. In an investigation conducted jointly by the department of chemistry and the Oahu Sugar Company, Ltd., in 1931, the writer (8) showed that the concentration of nutrients in the several parts of the



Figs. 11 and 12. Studies of the lime and magnesium content of leaves and sheaths of the cane plant as the crop proceeds. Results expressed on percentage of ash.

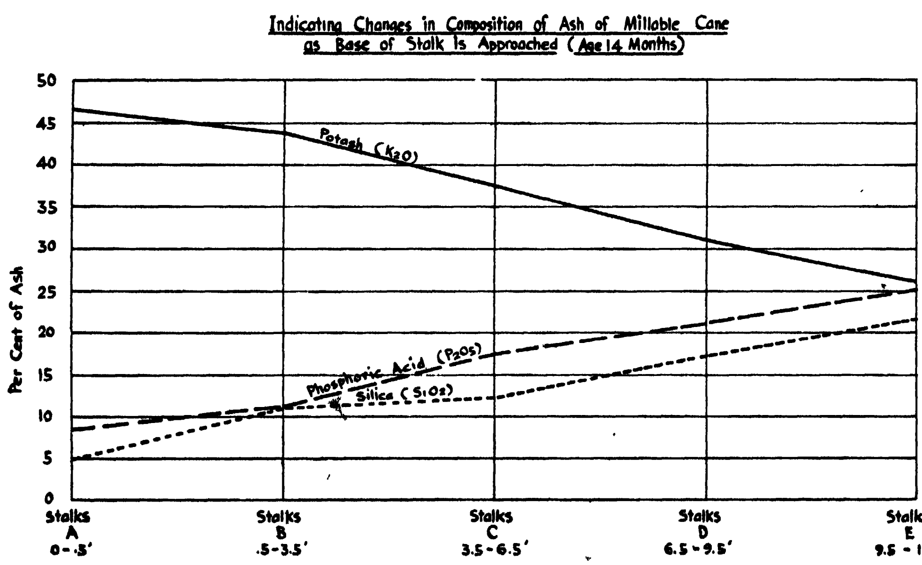


Fig. 13. The relationship shown here between the nutrients potash, phosphoric acid, and silica probably indicates the translocation of potash from the older to the more recently formed parts of the cane plant.

cane plant were generally lower in the ratoon than in the plant crop, the comparison being based upon the analysis of material obtained at harvest. This finding will receive attention in connection with the present investigation. The study

relative to the ratoon crop will be so extended as to permit the measurement of the rate of absorption of the principal soil nutrients by the total aerial portion of the cane plant. The results of this work are calculated to indicate not only the manner in which the mineral content of the plant changes with age and season under stable conditions of nutrient availability (i.e., without applications of potash and phosphoric acid), but also the periods of growth during which heavy demands are made upon the soil for these materials.

Nothing approaching a complete exposition of the findings of this study has been attempted at this time. Rather has it been the purpose of this paper to point out the high lights of the preliminary results, something of the need for such information, its practical application and to defer additional discussion pending further progress.

Note: The writer wishes to express his appreciation to Dr. Hance and Mr. Davis of this department for assistance and counsel, and to Messrs. Doty and Sa Ning of the department of agriculture for the installation, care and harvesting of the experiment.

Summary

1. A study has been made at monthly intervals of the effect of age and season upon the chemical composition of the sugar cane plant.

2. Graphs are presented which illustrate the changes occurring in the nutrient content of leaves and leaf sheaths with age and season.

3. The concentrations of the elements for which analysis was made were found to vary greatly, in a generally orderly manner, with the development of the crop.

4. Marked similarities exist in the direction and rate of change of concentration of certain of the elements investigated.

5. The nutrient content of leaves and sheaths was generally found to be very similar throughout the course of the crop.

6. The ash content of the stalk falls off progressively in the direction of the older region of the stalk.

7. The silica and phosphoric acid content of the ash of the stalks increases very markedly as the base of the stalk is approached, while that of potash decreases in an equally pronounced manner.

8. The concentrations of nitrogen, phosphoric acid, potash, lime and magnesia are greater in the region of the growing point than in any other part of the cane plant. With the exception of this portion of the stem the concentrations of all the elements for which analysis was made are highest in the dry matter of the leaves and sheaths.

9. Abrupt changes in direction of change of nutrient content of leaves and sheaths with the development of the crop are generally coincident with (a) attainment of mature foliage and commencement of stalk formation (3 months), (b) preparation of crop to tassel (15 months), and (c) lala development (20 months).

10. The order of nutrient concentrations in various parts of the cane plant is generally as follows:

LEAVES

$$SiO_2, K_2O > N > P_2O_5 > CaO, MgO$$

SHEATHS

$$K_2O, SiO_2 > P_2O_5 > N > MgO > CaO$$

REGION OF GROWING POINT (STALKS A)

$$K_2O > N > P_2O_5 > MgO > SiO_2, CaO$$

MATURE STEM (STALKS C)

$$K_2O > P_2O_5 > SiO_2 > MgO > N > CaO$$

11. The need for further study of factors influencing the mineral content of sugar cane in relation to disease, plant food deficiencies and undesirable conditions resulting from unbalanced nutrient content is discussed.

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CHEMICAL COMPOSITION OF PLANT PARTS

Age (Months)	Plant Part	Ash % D.M.	SiO_2 % D.M.	SiO_2 % Ash	CaO % D.M.	CaO % Ash	K_2O % D.M.	K_2O % Ash	MgO % D.M.	MgO % Ash	P_2O_5 % D.M.	P_2O_5 % Ash	N % D.M.
1	Leaves	6.78	1.24	18.4	.216	3.19	2.64	39.0	.322	4.77	1.03	11.8	1.54
	Sheaths	8.91	1.63	18.2	.119	1.34	3.32	37.2	.300	3.37	1.04	11.6	0.60
2	Leaves	7.68	2.61	34.0	.459	5.92	1.80	23.4	.448	5.83	0.655	8.53	1.93
	Sheaths	8.15	2.92	35.8	.310	3.79	2.09	25.6	.527	6.47	0.608	7.45	0.55
3	Leaves	8.10	3.45	42.7	.530	6.55	1.57	19.4	.433	5.35	0.658	8.15	1.40
	Sheaths	9.02	3.87	42.8	.360	3.99	1.77	19.6	.533	6.02	0.594	6.58	0.38
4	Leaves	7.40	2.60	35.2	.417	5.63	1.84	24.9	.386	5.22	0.766	10.35	1.41
	Sheaths	8.93	3.22	36.1	.320	3.58	2.36	26.4	.438	4.90	0.647	7.24	0.49
5	Leaves	6.72	2.41	35.9	.400	5.95	1.61	24.0	.379	5.48	0.630	9.38	1.29
	Sheaths	7.62	2.32	30.4	.289	3.79	2.22	29.2	.420	5.51	0.625	8.20	0.46
	Stalks A	10.15	.352	3.47	.336	3.32	4.37	43.2	1.035	10.20	1.10	10.78	1.39
6	Leaves	6.03	1.79	29.2	.266	4.33	1.93	31.5	.297	4.85	.592	9.67	1.11
	Sheaths	7.18	1.91	26.6	.232	3.23	2.47	34.5	.335	4.66	.548	7.64	0.424
	Stalks A	11.03	.352	3.19	.261	2.37	5.06	45.8	.965	8.75	1.13	10.22	1.41
7	Leaves	6.86	2.09	30.2	.329	4.80	2.02	29.4	.311	4.53	.568	8.30	1.09
	Sheaths	7.45	1.84	24.7	.224	3.01	2.64	35.4	.301	4.04	.475	6.37	0.379
	Stalks A	10.85	.268	2.47	.322	2.97	4.91	45.3	1.015	9.35	1.06	9.74	1.32
	Stalks B	2.09	.367	17.6	.064	3.04	.700	33.5	.179	8.57	.313	15.0	0.244
8	Leaves	5.72	1.27	22.2	.220	3.85	2.13	37.2	.235	4.10	5.27	9.22	0.923
	Sheaths	7.14	1.63	22.8	.222	3.10	2.74	38.3	.279	3.91	.465	6.52	0.326
	Stalks A	11.75	.313	2.67	.575	4.88	5.30	45.2	.972	8.27	1.065	9.08	1.32
	Stalks B	2.27	.319	14.1	.065	2.85	.852	37.6	.180	7.96	.321	14.15	0.177
9	Leaves	6.17	1.78	29.1	.231	3.76	1.98	32.2	.220	3.58	.553	9.02	0.892
	Sheaths	7.42	1.71	23.1	.171	2.31	2.76	37.2	.262	3.53	.505	6.83	0.295
	Stalks A	12.45	.363	2.92	.360	2.89	4.65	37.4	.940	7.55	1.11	8.96	1.15
	Stalks B	2.68	.325	12.1	.071	2.65	1.04	38.6	.205	7.65	.407	15.2	0.171
10	Leaves	5.28	1.22	23.1	.145	2.74	2.27	43.0	.199	3.77	.492	9.30	0.829
	Sheaths	7.48	1.66	22.2	.179	2.39	3.20	42.7	.211	2.82	.453	6.06	0.269
	Stalks A	12.38	.361	2.91	.426	3.43	5.99	48.4	.928	7.50	.963	7.48	1.13
	Stalks B	3.11	.292	9.38	.067	2.15	1.33	42.7	.192	6.17	.378	12.15	0.163
	Stalks C	1.25	.212	16.95	.031	2.48	0.386	30.8	.098	7.84	.270	21.6	0.080
11	Leaves	5.19	1.38	26.6	.153	2.95	1.95	37.6	.171	3.29	.482	9.28	.883
	Sheaths	7.54	1.95	25.9	.157	2.08	3.16	41.9	.189	2.51	.440	5.83	.286
	Stalks A	11.39	.428	3.76	.453	3.98	5.48	48.1	.876	7.68	.918	8.05	.978
	Stalks B	3.50	.340	9.70	.075	2.14	1.59	45.4	.203	5.79	.377	10.75	.162
	Stalks C	1.42	.228	16.05	.040	2.81	.482	33.9	.111	7.82	.272	19.15	.072
12	Leaves	5.46	1.40	25.7	.154	2.82	2.20	40.3	.177	3.24	.475	8.70	.842
	Sheaths	7.52	1.99	26.5	.170	2.26	3.07	40.8	.186	2.48	.429	5.71	.281
	Stalks A	11.08	.412	3.71	.403	3.64	5.25	47.3	.807	7.27	.839	7.57	.940
	Stalks B	2.79	.303	10.85	.080	2.86	1.20	43.0	.191	6.87	.330	11.85	.141
	Stalks C	1.44	.209	14.50	.042	2.92	.514	35.6	.107	7.42	.282	19.58	.089
13	Leaves	6.56	2.10	32.0	.216	3.29	2.33	35.5	.200	3.05	.465	7.08	.879
	Sheaths	8.51	2.39	28.1	.191	2.24	3.34	39.2	.207	2.43	.396	4.65	.327
	Stalks A	11.77	.439	3.74	.467	3.98	5.41	46.0	.900	7.63	.922	7.82	1.08
	Stalks B	3.08	.327	10.60	.069	2.24	1.35	43.8	.182	5.98	.325	10.57	.170
	Stalks C	1.68	.230	13.7	.037	2.20	.616	36.6	.111	6.61	.294	17.50	.103
	Stalks D	1.15	.220	19.1	.038	3.30	.347	30.2	.109	9.48	.278	24.2	.086
14	Leaves	6.00	1.87	31.2	.191	3.19	2.12	35.3	.177	2.95	.450	7.50	.859
	Sheaths	6.95	2.01	28.9	.170	2.45	2.65	38.1	.166	2.39	.417	6.00	.340
	Stalks A	9.37	.460	4.92	.374	3.99	4.36	46.5	.777	8.28	.785	8.38	.849
	Stalks B	3.06	.339	11.1	.084	2.74	1.34	43.8	.190	6.22	.338	11.05	.166
	Stalks C	1.59	.229	14.5	.047	2.96	.600	37.7	.105	6.60	.275	17.3	.096
	Stalks D	1.23	.213	17.3	.043	3.49	.383	30.9	.016	1.30	.258	21.0	.091
	Stalks E	1.04	.222	21.5	.041	3.94	.273	26.3	.016	1.54	.258	24.8	.087

NOTE. D.M. refers to Dry Matter.

CHEMICAL COMPOSITION OF PLANT PARTS—Continued

Age (Months)	Plant Part	Ash % D.M.	SiO_2 % D.M.	SiO_2 % Ash	CaO % D.M.	CaO % Ash	K_2O % D.M.	K_2O % Ash	MgO % D.M.	MgO % Ash	P_2O_5 % D.M.	P_2O_5 % Ash	N % D.M.
15	Leaves	7.36	3.74	50.8	.382	5.19	1.51	20.5	.245	3.33	.363	4.93	1.06
	Sheaths	4.82	1.85	38.4	.165	3.42	1.44	29.9	.171	3.55	.277	5.75	.288
	Fuzz	5.75	2.18	37.9	.226	3.94	1.21	21.1	.345	6.00	.753	13.1	1.60
	Tassel-Stalks	4.40	.200	4.55	.038	.863	2.15	48.8	.169	3.84	.586	13.3	.767
16	Leaves	7.55	3.60	47.7	.329	4.36	1.61	21.3	.227	3.01	.463	6.13	.907
	Sheaths	6.84	2.75	40.2	.208	3.04	1.92	28.1	.243	3.55	.379	5.53	.336
	Fuzz	7.26	3.63	50.1	.210	2.90	1.12	15.5	.362	4.98	.702	9.70	1.35
	Tassel Stalks	4.19	.362	8.63	.052	1.24	1.95	46.5	.132	3.15	.464	11.1	.364
18	Leaves	6.50	2.07	31.8	.113	1.74	2.25	34.6	.139	2.24	.579	8.91	.642
	Sheaths	8.06	2.04	25.3	.095	1.18	3.08	38.2	.155	1.92	.630	7.82	.264
19	Leaves	6.78	2.16	31.8	.221	3.26	2.14	31.6	.250	3.68	.675	9.96	.970
	Sheaths	8.37	2.07	24.7	.173	2.07	2.94	35.2	.260	3.11	.822	9.83	.332
20	Leaves	8.57	3.87	45.2	.421	4.92	1.79	20.9	.310	3.62	.619	7.23	.968
	Sheaths	8.82	2.42	27.5	.187	2.12	2.88	32.7	.284	3.22	.825	9.35	.331
21	Leaves	7.65	3.57	46.7	.371	4.85	1.57	20.5	.283	3.70	.624	8.17	.902
	Sheaths	7.82	2.29	29.3	.191	2.44	2.47	31.6	.249	3.19	.725	9.28	.350
22	Leaves	7.00	3.15	45.0	.290	4.13	1.61	23.0	.191	2.73	.622	8.89	.702
	Sheaths	7.78	2.31	29.7	.185	2.37	2.61	33.5	.209	2.68	.705	9.05	.310
23	Leaves	6.14	2.19	35.7	.186	3.03	2.00	32.5	.151	2.46	.568	9.25	.662
	Sheaths	7.72	2.16	27.9	.141	1.83	2.86	37.1	.161	2.09	.710	9.20	.300
24	Leaves	7.08	3.33	47.0	.246	3.48	1.73	24.4	.154	2.18	.575	8.12	.698
	Sheaths	7.28	2.22	30.5	.163	2.24	2.48	34.0	.172	2.36	.658	9.03	.264

NOTE: D. M. refers to Dry Matter.

Water*

By CHARLES S. JUDD
Territorial Forester

WATER! The cry of the wounded on the battlefield, of the traveler lost on the desert, and of shipwrecked mariners adrift in a boat; that which is usually taken for granted, and is never missed until the well goes dry; the greatest solvent known; a good servant, but a most powerful and destructive master; the lack of which is the most effective agency in limiting human settlements; a powerful factor in changing the configuration of the earth's surface; and what for centuries was considered and is still spoken of as an element, and what, when pure, is colorless, tasteless and odorless.

When the Indians of the southwestern deserts, where water was extremely scarce and was used with the greatest of parsimony, visited the white man's settlements for the first time and saw water produced by the mere turning of a faucet handle. like the water of Meribah which was brought forth out of the rock by the rod of Moses, they thought it magic.

Scarcely more than three years ago, immediately after a very severe major operation, my surgeon prescribed that in order to survive I must refrain from the use of water for two days. It was then that I knew for the first time what thirst really is and during my day and night dreams, I thought of a cool spring that gushed from a volcanic dike at the head of Waiahole Valley. of the dew-bedecked water bottle in the ice box at home, and of the crystal-clear streams of cool mountain water that I had often come across in my wanderings. How wonderful was the refreshment of the water from a tiny piece of melting ice which I was permitted to have toward the end of the second day.

When famished for water in the old goat-hunting days on the Kauai cliffs, muddy water collected in the imprint of a wild bullock's hoof has been more pleasing even that what, I am told, the finest of champagne tastes like. How grateful were we, in the old Honolulu days of inadequate surface water supplies, to dip the muddy water from the family bathtub, which the wise forethought of a provident mother had filled anent the emergency.

Water exists in the greatest quantity of any single substance and is absolutely necessary for our existence. It covers five-sevenths of the whole earth, and if the surface of the earth were smooth, without mountains or valleys, water would cover its surface uniformly to a depth of about two miles.

Plants and animals require water in surprisingly large quantities. It has been figured that a sunflower plant will use two pounds of water a day and the amount of water transpired each year by one acre of normal beech forest has been estimated at 1,200 tons. This is the equivalent of about 10.6 inches of rainfall per year. Very few forest types, however, transpire as much moisture as beech.

* Address by the retiring President, Hawaiian Academy of Science, Annual meeting, 1933.

We can realize how essential water is in sustaining life when we consider that the human body is about two-thirds water. Man can live without food for about two months, but can do without water only two or three days. As examples of the water content of the foods we use, rich milk contains about 87 per cent water, eggs 65 per cent, and cucumbers 97 per cent. For every pound of grain that is grown, for every pound of meat that is produced, many times their weight in water is required. A pound of bread is the equivalent of about 2 tons of water used by the growing grain. A pound of beef is the equivalent of 15 to 30 tons of water consumed by the beef animal, both directly and indirectly through feed. And if you are inclined to revel in vivid statistics, consider this: the adult who eats 200 pounds of bread and 200 pounds of meat in a year, consumes the equivalent of 4,400 tons of water—which ought to be enough to drown both him and the statistician who figured it out.

Water sprouts the seeds and feeds plants. A tree, like other forms of life, is engaged in the constant circulation of fluid through its tissues. Life processes, animal or vegetable, can go on only so long as each individual cell is surrounded by a fluid containing nutriment. To meet this demand and to provide for a large amount of evaporation, a tree passes up a great deal of water and this water, in the larger species of trees, will have to be lifted 200 and even 300 feet.

How is this supply of water taken to the top of such tall trees? This question, in the present stage of man's knowledge of physics, cannot be answered. We do not know, but Charles D. Stewart in the April, 1929, issue of *The Atlantic Monthly,* has presented some most interesting conjectures in connection with this phenomenon:

The lamp-wick principle, capillary attraction, will not go far in raising water. Water rises in a capillary or fine tube to a height in proportion to the fineness of the tube; and the viscosity of water is such that if the tube is very fine it will not rise at all. Capillary attraction would not raise water to the top of even a moderate-sized tree.

Root pressure or osmosis, a sort of powerful absorption due to unbalanced chemical pressure between the soil outside of the root membranes and the denser solute inside of it, has been taken into consideration. By cutting off a plant near the ground and fastening a glass tube upright on the stem, it is possible to ascertain the height to which its sap will rise by pressure from below. Under favorable conditions a grapevine will exert a pressure sufficient to raise a column 36.5 feet, while a birch has tested as high as 84.7 feet. This might seem a promising line of inquiry were it not that root pressure takes place in woody plants, in temperate zones at least, only in early spring, and especially in the morning.

It has been found that when a tree is evaporating the greatest quantities of water, on dry, hot days of summer, there is no root pressure whatever. Even if such pressures were not seasonable and unusual, they would not serve to send water to the tops of the tallest tree.

It has been proved beyond question that the rise of water in the tubes of a tree is caused by a pull from above. The law of an ordinary suction pump limits the lift of water to 33 feet. No invention can be made which will pull more than the laws of physics will enable it to. And 33 feet falls far short of reaching the top of a sequoia.

But water has got to go up those tubes to the top of a tree. It will and does. This being the case, scientists began to consider whether water in thin columns, as in these fine tubes in the sapwood, has not an actual power of coherence, a tensile strength, sufficient to stand a strong pull. Possibly, after all, water may be drawn up from the top as if it were a rope. Strange as it may seem, experimentation has gone quite far in

proving this to be the case. It seems that such a column of water has a power of coherence great enough to withstand the pull. And the osmotic force in the leaves, a strong pull of absorption, might be sufficient to raise the columns of water to the necessary height.

This is the theory that at present comes nearest to satisfying scientific minds but here a further difficulty presents itself. The rise of water depends upon evaporation. This flow persists when the air is saturated or the leaves are entirely submerged in water.

The rise of water in tall plants is a mystery but it is life that is at work.

It is when we consider the tree from the standpoint of evolution—a plant made to conquer difficulty, a sea creature living on land, a machine progressively put together to achieve the nearly impossible—that we begin to see its lofty waterworks in their full significance.

The tree was an idea in nature, a very bold and original idea based upon a fundamental patent; and the steps leading up to it were four. First came the primitive water plants, the thallophytes, floating freely about or, according to the latest views, living in the saturated soil along the shore. Second came the amphibious plants, such as the mosses; third the woody plants beginning with ferns; and fourth the most modern woody and two-sexed plants of this highly mechanized vegetable age.

The mosses crawled on their bellies up toward the dry land. Stealthily and cautiously the moss plant draws away from the water's edge, lying low. Finally the great idea came to pass in the form of the fern. Here was a vegetable mechanism with true, running roots, which the moss has not; and it possessed a woody stem provided with tubes for conducting water. With the invention of the fern, piping the water upward, while the roots struck down to bring it from below, nothing more was necessary to the making of a tree. It only remained for the stock company of cells to go ahead and, in modern parlance, construct a "bigger and better" plant.

Every cell in the top of a tree continues to be immersed in the life-giving water. Between a cell in the sea and one in the topmost twig there is no essential difference in situation. And the reason is that everything is done to control evaporation and hold it within bounds. Every leaf is coated with a preparation that most effectually seals it. Air can enter and water escape only through microscopic openings called stomata on the under sides of the leaves; and every stoma is capable of being opened or closed according to conditions. The whole trunk and every limb of the tree are jacketed in the protective, suberized bark. There is nothing more waterproof than bark, more stubbornly impermeable. It is because cork is so waterproof that it makes stoppers for bottles and gaskets for engines. It is because it is so impermeable that it is ground up to make linoleum. A tree, from head to foot, is armored against evaporation. Consequently its cells, though they hang in the very eye of the sun, are in water as wet as that which surrounded them in the sea.

Water is a compound of hydrogen and oxygen and although it is commonly spoken of as a liquid, it exists also in solid and gaseous forms. Water vapor is a normal component of the atmosphere, and when as much water has evaporated into the air as it is possible for it to hold, the atmosphere is said to be saturated. Under ordinary atmospheric pressure water becomes a vapor at 212° F. and solidifies at 32° F.

A feature of water, important in physiography, is its exception to the general law of expansion by heat. It is at its greatest density at 39.2° F. When heated from the freezing point, it contracts until it reaches 39.2° F., after which it expands. Conversely, when cooled from 212° F., it contracts until it reaches 39.2° F., when it again begins to expand. This expansion with freezing is of great importance, for it keeps the ice on top of the heavier masses of water and thus prevents the solid freezing of lakes and ponds, which would cause the death of the

animal life in their waters. On the other hand, it causes, in climates less salubrious than ours, the bursting of water pipes in freezing weather.

The waves of the sea exert almost unlimited power and could some device be found for using this power in operating machinery, the expense of many manufacturing processes might be reduced.

Every sea captain and veteran mariner knows of the terrific force of water as manifested in the waves of a storm, and many a ship has limped into port with her superstructure smashed and demolished by the relentless energy of the ocean waves.

The power from water was formerly used in hydraulic mines to wash gold-bearing gravel from the hills, and the same principle is used today for moving and settling soil in the construction of earth dams. This power has more lately been put to even intenser use and in the Westinghouse research laboratories tiny jets of water cut through the hardest steel alloys in a test for the purpose of determining the rate at which different metals wear away as they cut through a moisture-laden atmosphere at high speed. The hardest metals seem as soft as cheese when subjected to this water test.

Water is so slightly compressible that for most practical purposes it may be regarded as incompressible. For this reason it is utilized successfully in the hydraulic press, which depends for its action on the principle that a pressure exerted on any part of the surface of a liquid is transmitted undiminished and equally in all directions through the mass.

To make water available, huge expenditures are often made. An example of this is the new water supply system for Southern California, where water is at a premium. The new Colorado River aqueduct is the largest waterworks project in the world and will be 265.5 miles long from the Colorado River to a terminal reservoir and requires a pumping lift of 1,563 feet. Its carrying capacity will be one billion gallons per 24 hours. Construction cost, including interest charges, is estimated at $206,000,000.

Water power is, perhaps, after wind power, the most natural and at the same time the most economical source of energy. The term water power is something of a misnomer. The real agent is gravity, the fluid itself being the medium through which the action of gravity is transmitted to the prime mover. The total capacity of water-power plants in the United States at the end of 1930 was 14,884,667 horsepower.

We are indebted to the movement of water in the form of ocean currents not only for a marked influence on the distribution of temperature, but also for a wide dissemination of plants from land to land over the face of the globe. Seeds adapted to resist the effect of sea water may be carried by ocean currents to new lands. The seed of the milo, for example, can float a year in sea water without loss of germinative capacity.

Fourteen years after the destruction of all life on the volcanic island of Krakatao, fifty-three phanerogams had reached the island, from which it was estimated that 60 per cent had arrived by ocean currents, 32 per cent by wind agency, and only 4 per cent by fruit-eating animals or by man.

Dr. Forrest Brown has pointed out that we are indebted to Brazil for the derivation of the Hawaiian thistle tree (Hesperomannia) and that it must have been

brought here from the east coast of South America by ocean currents on its long journey through what is now the Panama Canal region when, during the Eocene period, this connecting link between North and South America was under water.

Ocean currents, therefore, as compared with such other agencies as winds and frugivorous birds, would appear to be, by far, the most efficient agency in the dispersal of seed-bearing plants.

To the ocean waters of this globe we are indebted for a large share of our food supplies by reason of the animal and plant life which they sustain. We are indebted to these waters for our maritime commerce and comparatively cheap methods of transportation which began after our forebears once rid themselves of the notion that the earth was flat and that if you should go too far out to sea you might fall off the edge of the world into oblivion. This method of cheap transportation by water extends far inland on some of our continents by reason of the large navigable rivers which penetrate their way to the ocean. These rivers became the early avenues of trade, which eventually prompted the improvement of river channels and ultimately the construction of canals.

A manifestation of the force of water in combination with wind is the so-called "waterspout," which is really a cloud and not the imagined solid column of water. A waterspout is the funnel cloud of a tornado and is formed in the same manner by the air whirling at terrific speed—perhaps 200 to 300 miles an hour. A partial vacuum is created by the centrifugal action of the vortex, the water vapor in the air is cooled by expansion and condenses to liquid drops. While it is true that above a certain height the column of a waterspout is only a cloud and is sometimes so thin that distant objects can be seen through it, the base of the spout is always surrounded by a quantity of flying spray, whipped up from the surface of the sea. In some cases, this water is carried up hundreds of feet.

Thus, a vessel running into a waterspout is generally deluged with water, and if the spout collapses at the moment of encounter, a veritable cloudburst occurs, such as might easily swamp a small vessel. In the early morning of March 30, 1923, the White Star liner *Pittsburgh,* while in mid-Atlantic, was struck almost head-on by a spout which the deck officers asserted was 40 to 50 feet wide and more than 70 feet high, as water filled the crow's nest that far above the waterline. Many tons of water dropped upon the forward superstructure. The bridge was wrecked, the chart room badly damaged, electrical connections were destroyed and the officers' cabins flooded.

The large amount of water that may be discharged by a waterspout is indicated by a case in which the spout came ashore at Swansea, Wales, in September, 1886. A spout was seen to travel from the adjacent bay to an eminence called Kelvey Hill. The latter is about 650 feet high and the upper part is almost vertical, while on the lower slope some rows of houses had been built. When the spout struck the hill great torrents of water rushed down the slope, burst through the upper row of houses and carried all their movable contents into the street below. Many people were washed from a back room into a front room, out of the door and down the hill. The amount of earth and rocks washed down by the torrent was estimated at 8,000 tons.

All civilization has passed through periods of excessive precipitation that have caused floods. The Bible tells us that life on earth was saved from water only by

Noah and his ark when forty days and nights of rain flooded the cradle of civilization.

It has been estimated that the yearly discharge by the streams on the mainland of the United States into the sea is 500 million tons of suspended material and that twice this amount is stranded upon lower slopes and deposited over flood plains, in the channels of streams, and even in the basins of reservoirs, where it is not needed and not wanted.

Furthermore, it is not known how much erosional detritus enters the ocean as drag material swept along the bottoms of streams. This debris thus swept along the bottoms of many streams travels rather after the manner of waves or of sand dunes drifting before the wind. Some particles of the bed load slide; many roll, the multitude make short skips or leaps, the process being called saltation. Saltation grades into suspension.

The almost inconceivable damage wrought by floods has been unquestionably increased in a great measure by the works of man in the stream channels, along the banks, and across the river valleys. Although the presence of enormous volumes of water at the times of flood may be considered nothing more or less than the acts of nature, still a large share of the blame for the resulting damage must be laid to man, not only for the positive harm done by the works of municipal and rural improvements, but also because of interference with the natural soil protecting cover.

Soil vandalism is the greatest economic problem facing the conservation forces of the United States today. Despite vast expenditures for agricultural education, a large part of the good farm soils are being despoiled at an alarming rate. The despoliation of our streams, while serious enough in itself, is merely a symptom, an inevitable concomitant of what is taking place upon the land.

The plan of stream control upon the land implies working with nature to repair the damage to land and to stream, instead of erecting enormous barriers against her relentless forces; it means an intelligent compromise with nature in order that land use may proceed safely and largely unimpeded, instead of a stupid conflict of brute strength with her. To some extent it probably means taking land which never should have been cultivated out of cultivation to be employed for pasture or forest.

The power of water as manifested in abnormal soil erosion constitutes one of the greatest problems now facing the United States. Under normal conditions rock decay keeps pace with soil removal in many places. Removal of forest growth, grass and shrubs, trampling by livestock, and breaking the ground surface by cultivation accentuate erosion to a degree far beyond that taking place under average natural conditions, especially on those soils that are peculiarly susceptible to rainwash. Under these conditions, soil removal by the rains exceeds the rate of natural soil formation and the soil that is washed out of fields can not be restored, except by those exceedingly slow natural processes of soil building that require, in many instances, centuries to develop a comparatively thin layer. Experts assert that the minimum rate of soil formation is not greater than one foot in 10,000 years.

Not less than 126 billion pounds of plant food material is removed from the fields and pastures of the United States each year. Most of this loss is from cultivated and abandoned fields and overgrazed pastures and ranges. The value of

these plant food elements, considering only phosphorus, potash and nitrogen, exceeds 2 billion dollars annually.

Of the heritage of over 650 million acres of readily arable land on the mainland of the United States, at least 21 million acres have gone out of cultivation because of destructive erosion alone. What it took nature 3,000 years to produce, man is now destroying in the short period of one generation.

The area of land eroded in the United States already exceeds the total area of arable land in Japan. The agricultural soil of a country is the nation's most valuable natural resource, yet less interest is usually shown in soil conservation than in any other conservation problems. The great volume of silt contributed to the floods of the Mississippi comes from the misuse of farm and pasture lands. The cure is to deal with the rainfall on lands upon which it descends and induce it to go into the soil in place instead of running off laterally and carrying the soil with it. The way to stop surface run-off is to require each parcel of land to take up its share of rainfall.

All the crops in the United States annually remove about 6 billion pounds of plant food from the soil, but erosion annually removes about twenty-one times as much.

As an example of what has happened on account of erosion, one county in the Atlantic Coastal Plain has 70,000 acres of former good farm soil, which, since clearing and cultivation, has been gullied beyond repair. In one place, where a school house stood forty years ago, gullies having a depth of 100 feet or more are now formed and these finger through hundreds of acres of land, whose reclamation would baffle human ingenuity. There are many deep gullies with steep or perpendicular sides on which no vegetation can find a footing. One of the largest has developed within the memory of the present generation, having started with the formation of a small gully from the run-off of a barn.

The decrease in acre yield of wheat in parts of the Wheat Belt, decrease in acre yields of corn in many sections of the Corn Belt, and decrease in acre yields of cotton in numerous localities in the Cotton Belt can be attributed largely to soil washing.

The question might well be asked: Where is a nation headed that is destroying the fertility of farm lands at a rate of 3,000,000 acres per annum?

When the mellow top soil is gone, with its valuable humus and nitrogen, less productive, less permeable, less absorptive, and more intractable material is exposed in its place. As a rule this exposed material is the raw subsoil, which, to be usable, must be loosened, aerated, and supplied with the needed humus to put it into the condition best suited to plant growth.

The practical problem lies almost wholly in retaining and passing into the soil the maximum of the precipitation. It is obvious that the erosional debris entering the streams adds to the volume of the water and increases the intensity of floods. Methods of soil conservation, chiefly terracing the land and the growing of trees, grass and other soil-binding plants, have been found effective in slowing down or controlling soil erosion by causing more water to be retained in the surface soil and to be stored in the subsoil.

Soil conservation is therefore somewhat synonymous with moisture conservation. Nothing will hold back all the water, of course, but enormous quantities can

be held temporarily or stored for summer crop use. Soil conservation, therefore, should be an important adjunct of any long-continued system of flood control.

The part of the rainfall which is absorbed into the soil where water is available in wells and springs and maintains the regularity of streams is the part which sustains life for both plants and animals.

A vegetative cover checks the excessive run-off by breaking the impact of raindrops on the ground, by intercepting a portion of the moisture before it reaches the surface of the ground, by extracting some of the moisture from the soil, so that it is capable of absorbing more water when rainfall occurs than would otherwise be possible, by adding to the humus content and loosening the consistence of the soil and thereby improving its absorptive and water-holding capacities, by the direct interposition of leaves and stems which help to keep the run-off spread out instead of concentrating its volume in gullies and which form nuclei around which other fragments of dead plants and other material collect to form miniature dams and terraces and further check and retard the run-off and by straining out and reducing the quantity of fine soil material in the water and thus rendering it more free to seep into the soil.

Vegetation is our most dependable ally in the control of the absorption of precipitation waters. The mantle of vegetation maintains, when unimpaired, what may be termed a geologic norm of erosion. We have no way of stopping effectively this geologic norm of erosion which, however, for well-vegetated regions is not excessive. The destruction of vegetation and conditions for its renewal may bring about, in inclined and steep topography, erosion which is much in excess of the geologic norm. Only this excess erosion is within human power to control, yet it may reach stages where control is beyond practical possibilities.

The extent of water control on watersheds is measured by the possibility of controlling erosion in excess of the geologic norm of erosion. Water control here is referred to watersheds and not to the engineering works of dikes, dams and the like. In other words, we have a measure of possible water control expressed in the silt content of run-off waters. We can measure our success in water control by our success in erosion control.

The irrigation problem in western United States is being further complicated by the silting of streams and storage reservoirs. The Elephant Butte reservoir on the Rio Grande River in New Mexico after seventeen years of use, already has 15 per cent of its storage capacity occupied by silt, which has depreciated the original construction cost of $4,536,000 to the extent of $680,000. The Roosevelt Reservoir in Arizona has been silting at a rate of approximately 7,800 acre-feet per annum, or about 0.5 per cent of the total capacity. The Boulder Dam will accumulate silt at a rate of not less than 196,000 acre-feet per annum. The average construction cost for an acre-foot of storage in Boulder Dam when completed will be about $3.00, or, in other words, approximately $580,000 of investment will be destroyed annually by silt deposits. By the end of the fifty years, when it is expected the original cost finally will have been paid, $29,000,000 of investment, in addition to the interest, will have been taken up by silt.

The West, thus, is faced with the reality of many huge engineering undertakings becoming the repositories of silt removed from the watersheds. It is true that a portion of this silt is the result of natural erosion, but there is abundant evi-

dence that erosion has been accelerated by depletion of plant cover on the watersheds.

The capacity of the soil to absorb and retain water depends in considerable measure upon the presence of humus or organic matter in the soil. If a forest is cut off and burned, if a field is allowed to lose its topsoil and the contained organic matter, the absorptive capacity of the soil is reduced.

Water falling on such soil runs off rapidly, picks up part of the soil surface and carries it to the streams as sediment.

The result is: farms lose fertility and soil, small streams are choked, streams are filled with mud, navigation on larger streams is made hazardous and costly, and, most important of all, the region becomes impoverished for water. The ground waters are lowered, wells dry up, and springs disappear. Even though annual precipitation remains constant, we may have what approaches a drought, because the natural cycle of water and soil relationship has been shortened and disturbed.

Under such a situation it is necessary to revert to the slow natural process of restoring a plant cover that will check further erosion and gradually build up the organic matter and other elements of which the soil has been robbed. Forest cover, where it can be grown, is considered the best for this purpose, first, because of its superior ability to add organic matter to the soil as compared with other wild vegetation, and second, because a forest cover, if protected against fire, insures a more stable tenure of conditions favorable to rehabilitation than does a brush or herbaceous cover.

It is for the conservation of the soil resource quite as much as the water resource or timber resource that the forester argues the need of protection forests. An entirely new and much more sane conception of the function of humus in water absorption by soils has been developed by research foresters, so that one no longer thinks of the humus layer as a reservoir in itself, but as supplying the channels through which water may penetrate an otherwise largely impermeable soil.

From studies made by forest officers in California it has been proved that the forest litter greatly reduces the superficial runoff, particularly in the finer-textured soils, and this influence continues long after the litter is completely saturated; that destruction of the litter by such agencies as fire and the consequent exposure of the soil greatly increases the amount of eroded material and reduces the absorption rate of the soil; that suspended particles in run-off water from bare soils are filtered out at the surface and seal the pores and seepage openings into the soil sufficiently to account primarily for the marked differences in rate of absorption between bare and litter-covered soils; and finally that the capacity of forest litter to absorb rainfall is insignificant in comparison with its ability to maintain the maximum percolating capacity of soil profiles.

The important point is to keep the water clear and usable. In southern California usable water is water that is devoid of silt load, and there it is impossible to use water that carries heavy silt. In that region very little of the water for irrigation purposes is used and applied directly. As in Honolulu, where 90 per cent of the total water supply is obtained from underground sources, so in southern California 90 per cent of the water is pumped from underground basins. There, after the mountains were uplifted, the valleys were filled by material eroded out of these

mountains. Flats in California usually are filled-up former valleys or basins, and these filled basins of coarse detrital material, sometimes over 2,000 feet deep, furnish ideal storage basins. This keeps water pure, prevents its waste by evaporation or transpiration, and makes water available wherever wells are put down for irrigation, without cost for construction of aqueducts and canals. The most economical means of utilizing the water yield from the mountain areas is to put it underground. Particularly is this so because the rains come in winter. The important thing is to get water underground and water cannot spread and sink underground if it contains a large amount of sediment in suspension. Nor can it be spread and sunk underground if it comes in a peak storm flow. Then it can only be wasted to the ocean and once wasted it is lost. There water is worth $20.00 per acre-foot, about four times the value of water in Honolulu. It does not take a peak flow very long to cause a loss of one million dollars' worth of water. One principal means of the conservation of water in California, in Hawaii, and in other places, is to keep that water in such condition that it can be sunk underground.

Yet, prominent mainland engineers by analyzing figures of water measurements from certain watersheds which are extreme in character of soil and climate have recently attempted to generalize and have argued against the protective value of the forest under all conditions and unfortunately local individuals have been foolish enough to be influenced by these assertions sufficiently to disparage the work of forest protection carried on in this Territory. Among the conclusions in the Hoyt and Troxell report are the statements that "Forests do not conserve the water supply" and that the forest cover lessens the summer flow. They based their arguments on areas in Colorado and California which were in no sense normal. They omitted many facts that are vital to any logical and sane discussion of the subject of forests and stream flow, of watershed protection, and of the general utilitarian value of forested versus bare lands. While their proposal is carefully guarded and qualified, it tends to leave the impression that sufficient facts have been established to warrant so radical a departure as the elimination of protective forest cover.

Their revolutionary scheme, brought to its logical conclusion, is to obtain a higher yield of water by means of the simple expedient of removing the vegetation from the watershed, and with that, eventually, the soil as well.

Foresters were the first to demonstrate that forests use water in large quantities, as I have already mentioned. The increase in summer flow on the deforested watershed in the Wagon Wheel Gap experiment in Colorado is relatively small and may be fully accounted for by reduced interception of summer rains, occasioned by a forest cover prior to deforestation. This finding is used, however, to support by analogy the finding of a higher percentage increase of summer flow in southern California. The relative amount of increase as compared to the total flow is only 4 per cent, a figure less than the degree of accuracy which can be claimed for the stream gagings. Yet it is the discovery of this small increase which furnishes the basis of the conclusions and for the deduction that "the maintenance of forests for conservation of the water supply may have an effect exactly opposite to that desired."

The lack of adequate analysis and evaluation of the several factors that account for relatively small increase of summer flow invalidates both conclusions and deductions of their report for application, not only in California, but to other regions

as well, and the report presents an amazingly unbalanced picture of the many-sided water problem in that state. The lamentable inadequacy of the report is shown by special emphasis on summer flow variations which comprise in the study less than 5 per cent of the total annual flow, whereas problems affecting conservation of from 95 to 99 per cent of annual stream discharge are omitted from consideration.

As has already been pointed out, the principal method of conservation of water there is to sink storm run-off into underground detrital-filled basins. Water conditions necessary for maximum percolation of storm flow into underground basins are regulated flow and freedom from silt. With the burning or destruction by other means of the forest cover as advocated by these engineers, neither of these two conditions would be obtained for handling the greater part of the rainfall. Unregulated and muddy flood waters waste to the ocean and are permanently lost to use. We see this happen right here in our own islands.

The mantle of chaparral vegetation on the hills of southern California proves to be the most effective ally in regulating storm flow as well as in safeguarding costly flood storage capacity. Chief Engineer Eaton, of the Los Angeles County Flood Control District, places the value of chaparral cover above that of check dams and flood control dams. He states, "This normal mountain vegetation is the most effective and economical agency in the regulation of flood flows, increasing percolation and preventing erosion." And this is why the people of southern California spend millions in protecting this beneficial cover against destruction by fire or other agencies.

The time has not yet arrived when man may assume the audacity to start reversing the great constructive processes of Nature, for the sake of a temporary benefit, to water a few paltry additional acres of crops or to permit a few more people to congregate in the cities at the expense of increasing the flood run-off from burned watersheds, wastage to the ocean because of the silt load, consequent accelerated erosion, and damages to streets, bridges, railways, highways, orchards and other property. Losses of storm run-off from burned watersheds may exceed many fold total summer flow.

The beneficial value of our native forests on the water supply was recognized in Hawaii as far back as 1892, when the Hawaiian Kingdom passed Chapter 74, approved by Queen Liliuokalani on December 19, 1892. The preamble to the "Act to Exempt Certain Forest Lands from Taxation" reads as follows:

> WHEREAS, the preservation of the Forests is a matter of great public interest in consequence of their influence upon the water supply of the Kingdom. . .

The faith of the informed and observing people of the Territory in the value of forests because of their beneficial influence on the water supply has remained unshaken and this faith is manifested in the progress that has been made during the past quarter of a century in protecting unspoiled, native forest areas and reclaiming other areas on which the native forest has been destroyed by the zeal of ranching and agricultural industries in developing to their limit without any consideration for the perpetuation of the water supply. We have progressed to the extent of setting apart for watershed forests 1,027,299 acres, or about 25 per cent of the total land area of the Territory. We are now reforesting the open areas in this important forest estate at the rate of 30,000 trees per month and during the past

seventeen years have planted up 6,427 acres, which is only 24 per cent of the areas that are in need of immediate attention. Excessive erosion detrimental to the water supply is imperceptibly but surely taking place on some of our watersheds, and as long as this continues and as long as we have floods like that of 1930 in Kalihi Valley, which took a toll of eleven human lives, and have the effects of the mauka storms of 1923 and 1924 in Hamakua, when $95,000 damage was done to county roads and bridges alone, not to mention inestimable damage to the top soil by scouring and leaving a hardpan incapable of supporting even the poorest of weeds, we are still behind on our program of protecting properly our soil and water resources through forest extension.

The need for this class of work on the mainland, where soil erosion is lessening the productiveness of farms, causing disastrous floods, and interfering with hydro-electric development and with river navigation, has been recognized by our new President in Washington and in his good judgment he has seen fit to give forest work first attention as being necessary for the nation. His civilian conservation corps selected from the unemployed is today being recruited and trained by the army in camps to reforest national and state lands, to prevent soil erosion, and to put in fire and flood prevention improvements.

Water supply, floods, erosion and worn out soils—these are problems of the farm, the city, the county, the state and the nation. For many years forestry and forest lands have been recognized for wood, forage, outdoor recreation and beneficial influences upon water and soil. The recognition of water and soil problems in forest policy has been scarcely more than nominal. A good deal has been said but relatively little has been done in a real concrete way to give the water and soil problems the attention their importance warrants as a public responsibility. After all, the watershed problem is more a public responsibility than any other problem in the conservation of wild lands.

Once the few fundamental facts about erosion are understood, the remedies become perfectly clear. The situation is simply this: there is only one fundamental way to control navigation and regularity of streams and to maintain normal climatic conditions and abundant crops, and that is by retaining in the ground itself as much as possible of the precipitation falling on the ground, and by retarding as much as possible its run-off from the surface of the soil.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 20, 1933, TO SEPTEMBER 8, 1933.

Date	Per Pound	Per Ton	Remarks
June 20, 1933	3.36¢	$67.20	Puerto Ricos.
" 23	3.40	68.00	Puerto Ricos.
" 27	3.50	70.00	Puerto Ricos.
" 30	3.30	66.00	Cubas.
July 5	3.49	69.80	Puerto Ricos, 3.48, 3.50.
" 6	3.50	70.00	Puerto Ricos.
" 11	3.565	71.30	Cubas, 3.55, 3.58.
" 12	3.65	73.00	Philippines, Cubas.
" 19	3.60	72.00	Cubas.
" 21	3.50	70.00	Cubas.
Aug. 1	3.45	69.00	Cubas.
" 16	3.44	68.80	Cubas.
" 24	3.56	71.20	Cubas.
Sept. 6	3.635	72.70	Philippines, 3.65; Cubas, 3.62.
" 8	3.61	72.20	Cubas.

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(An asterisk preceding a page number indicates that the subject is illustrated.)

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